THE ROLE OF ACTION INFORMATION FEEDBACK IN THE ACQUISITION OF SIMPLE MOTOR SKILLS

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To my Parents

ABSTRACT

The role of visual action information feedback (AIF) in the control and retention of movements has been studied using three types of movement; bar pressing with a large gain on the visual display, timed movements with a display which showed time elapsed, and untimed movements of considerable extent with a visual display of the same size. In all three tasks control subjects received terminal information feedback (TIF), either visually or verbally, and in the third task a movement to a stop was also used.

The presence of a visual cue which was larger than the actual movement led to overestimation of the target pressure when the feedback was removed, even after extended practice. Subjects tended to believe that they had been inaccurate and that the bar had become stiffer when the feedback was removed. Halving the size of the visual display had no effect on test performance or subjective error. Inaccurate test performance was also found in the lateral displacement task, even when the visual cue was not necessary for the acquisition of the task, and subjects' estimations of error indicated that they felt they had overestimated in test.

In the timed movement task there were no differences between AIF and TIF trained subjects in either objective or subjective error. When the possibility of counting was removed by the addition of a shadowing task, AIF trained subjects tended to be less accurate after a delay than were TIF trained subjects.

These results are interpreted as evidence of visual dominance of other sensory systems in a long term learning situation, provided vision is used to code the movement early in learning, and are discussed in terms of the part played by visual feedback in the formation of motor programmes.

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Chapter 1

Feedback and motor programmes in movement control

1.1 Introduction: theories of movement control

As a movement is learned and becomes skilled there are changes in the way in which it is controlled. Initially the learner may guide a movement visually, or be instructed to attend to an auditory cue such as the change of engine note as the clutch of a car engages, and verbal instructions may be internalised and serve to cue the correct response. In addition an instructor may give information about extent and direction of error, or comment 'right' or 'wrong'. Eventually the learner becomes able to perform without the instructor's comments, without using internal verbal cues, and without conscious attention to the visual, auditory or other feedback from his movement.

A considerable body of research into movement learning has emphasized the effects of knowledge of the results of an action which are communicated to a learner by an instructor after the response has been made (Bilodeau 1966). These studies have attempted to discover the relationships between such factors as type, amount, and time of presentation of knowledge of results of an action on the subsequent ability to perform that action. Little emphasis has been placed on the ongoing control of movements as they are made.

Many studies have tended to use a simple graded movement in order to achieve results of more generality than could be afforded by studying specific tasks. Although this approach has been criticised by Broadbent (1971) and supported by Adams (1971) and agreement has not been reached, such movements do have "at least one of the fundamental marks of a skill, - an effector response is not merely set off by a receptor function but is guided and determined by it" (Bartlett 1948 p.31). This implies that sensory feedback is of great importance in the execution of skilled tasks and this is the basic tenet of some theories of movement control (e.g. Adams 1971).

Other theories deny that sensory feedback is necessary for movement control (Lashley 1917, Jones 1974) and suggest that after a certain level of skill has been attained the control of learned movements is central and predetermined or preprogrammed so that the movement may be performed automatically or without attention. It is this question of automatic control of skill which is at issue and there are several ways of answering it. Feedback theorists feel that control passes from the visual system to kinaesthesis so that attention can be directed elsewhere (Gibbs 1965), or that all available response-produced feedback continues to be used to evaluate performance so that no type of feedback may be removed without affecting performance (Adams 1971), while motor outflow theorists consider that the motor command is compared with a correct command copy to detect error (Laszlo and Bairstow 1971), or that the motor command function is altered directly by knowledge of results of action so that the programming involved is 'open loop' (Gundry 1975). Some preprogramming theory implies that neither visual nor kinaesthetic information is attended to for control of movement. It is suggested in fact, that response produced feedback is not necessary for the control of learned movements (Jones 1974).

A pre-determined pattern for a motor act has been called a 'motor programme', this is defined by Keele (1968) as "a set of muscle commands that are structured before a movement sequence begins and that allows the entire sequence to be carried out uninfluenced by peripheral feedback"(Keele 1968, p. 387). This does not necessarily mean that there is no detection of error while the programme is running as Gundry (1975) interprets it, but that such error detection is not based on peripheral feedback. Gundry suggests that theories of motor programming can be divided into two types - closed and open loop. In an open loop system there are no mechanisms for on-going eror regulation, while in a closed loop system error detection and correction operate. These latter are "self regulating by compensating for deviations from the reference" (Adams 1971, p. 116). The "reference" is common to most closed loop theorists and is called by some the "efference copy" after von Holst (1954), (Jones 1974a, Keele 1968, Roy and Martenuik 1974). In Adams' own theory the reference corresponds, not to the efference copy, but to a stored set of perceptual traces built up from the sensory feedback of previous responses. Thus there are two main types of closed loop theorists, those for whom performance of a well learned task can be judged by comparing feedback from the response with the sensory image of the correct response and those for whom the efference copy is compared with the standard of motor command required for the correct response.

A model which contains elements of both types of closed loop theory is that of Laszlo and Bairstow (1971). This model has four components:

1) The standard (STD) which is a global memory trace formed from information from instructions, previous knowledge about the task and information about the sensory consequences of the movement, so forming "the central comprehensive percept about the task" (p.242).

2) The motor programming unit (MP) which operates under the control of the standard and structures the motor commands.

3) Sensory feedback from the receptors to the STD. This is a peripheral feedback loop which can act as an error detecting system by providing information of sensory consequences of movement which is presumably compared to the desired feedback contained in the STD.
4) A central feedback loop from the output of the MP unit back to the standard. This corresponds to the efference copy and is used to detect commands in the output of the motor programme which diverge from the correct pattern of commands. This allows the STD, to modify the MP and so over trials without peripheral feedback performance could be maintained and even improved.

The motor programme unit in this model is not independent of sensory feedback when it is available but it organises output at two levels of control so that if knowledge of results were removed performance would continue and improve using both central and sensory feedback loops. If the sensory feedback loop were removed as well this would still be the case. Sensory feedback, while used if available, is not necessary to movement control.

The role of Sensory feedback is emphasized in Adams' (1971) theory, in which he suggests that there are two traces, a memory trace which selects and initiates action, and a perceptual trace which corresponds to a sensory image and which is compared with feedback from the response. Adams has two traces because theories such as that of Bernstein (1967) which have a motor command centre to define the response and with which feedback from the response is compared require that the mechanism which initiates the response also evaluates it. If the model both initiates and checks the response then error could not be signalled except following detection by an exteroceptive loop. In Laszlo and Bairstow's system the standard commands the MP unit and evaluates the feedback, error will therefore only be detected if the MP unit does not carry out the commands correctly and it is difficult to see why this should be so.

The memory trace is conceived of as preceding the perceptual trace and initiating the movement. It is a modest motor programme but its function is only to select and start a movement not to control a longer sequence. During practice the memory trace changes as more is known about the task so that a more accurate response can be chosen from a population of possible responses. The perceptual trace also develops over practice and is a sensory representation of the correct response. If knowledge of results is removed when the perceptual trace is well established then the feedback from the movement can still be compared with the perceptual trace so that performance can continue to improve.

There are considerable similarities between these two positions. Both utilise intrinsic feedback and knowledge of results during acquisition of a skilled response, both develop a standard of some kind during the acquisition, and both allow for error detection and continued improvement when knowledge of results is withdrawn. The main difference is the role of sensory feedback when KR is withdrawn, Adams considering it necessary while Laszlo and Bairstow accept that a central feedback loop may perform the same function.

Neither of these positions considers the relative use of kinaesthetic and visual feedback in the control of well learned tasks and this position has been based on what seemed obvious rather than on theoretical models (e.g. Gibbs 1965, Bahrick 1957). Adams' position does not strictly rule this out, indeed Roy and Martenuik (1973) have interpreted his theory as relating to the control of movement by kinaesthesis, but Adams considers all response-produced feedback to be important and suggests that the more there is in learning and retention trials the better retention will be.

The open-loop motor programme position requires the MP to operate without internal feedback loops, so if peripheral feedback were removed, accurate movements could still be made, but no improvement in performance would be expected. However, performance without sensory feedback could improve if knowledge of results were given, as the motor commands could be altered on the basis of the knowledge of results.

1.2 Movement without sensory feedback

One of the earliest and most basic studies in the 'inflow-outflow' debate was that of Lashley (1917), who reported experiments on a young man who had received a bullet wound to the spinal cord. The subject had anaesthesia of most of the leg afferents and was insensitive to flexion and extension of the knee. During testing the subject's leg rested over a rod at the knee so that the leg could move through an angle of 130°. A blindfold removed visual knowledge of movement and auditory cues were eliminated as far as possible. The subject was unable to hold his leg in any extended position for more than 10 seconds and was unable to report accurately on his own success at doing this. He could not recognise when his leg had been moved passively to a certain position and could not reduplicate the passive movements with any accuracy either of extent or direction. When tested on active movement, being asked to make movements of certain amplitude and then duplicate them, the subject was as accurate as a normal comparison subject. As there was no afference to account for these accurate estimations Lashley concluded that motor outflow was sufficient to control movement. In addition

Lashley found that rate and extent of movement were not related so that control of extent of movement could not be "determined merely by the control of duration of the excitation of the motor pathways" (p.186).

While the most controlled way to investigate the role of motor outflow might be surgically to deafferent a subject this is of course impossible, and if Lashley's fortunate accident (for science rather than the individual concerned) is to be the mainstay of a theory the question of whether his subject's leg was completely deafferented is of considerable importance. Lashley reports that there was no tendon reflex, that the leg could not be kept extended for more than 10 secs. and that the muscles did not accurately compensate for spring resistance when it was applied. However, passive movements of more than 25° per second were reported as movement, although direction and extent were not known, suggesting that some afferents may have been reaching the brain. Nevertheless most authors (Adams 1971, Keele 1968, Gundry 1975 and Jones 1974) agree that Lashley's result is evidence for some type of motor programme operating when there is no exteroceptive or kinaesthetic feedback. Simple movement can be controlled centrally.

Although humans may not be surgically impaired in the interests of research a considerable amount of evidence of the existence of motor programmes is drawn from studies of lower organisms. The ability of organisms lower than primates on the phylogenetic scale to perform motor acts without kinaesthetic feedback has been reviewed by Delong (1972) and is exemplified by the work of Wilson (1961) on the locust. Wilson studied the sensory control of the locust's wing movements. The removal of whole wings or parts of wings had no effect on the patterning of movement of the remaining wings or wing stumps. The removal of wings, legs, abdomen and wing sensory nerves still left the wing stumps contracting in the rhythmic pattern of normal flight when the head was exposed to wind, which is a cue for flight in the locust. Not only does the wing movement remain unchanged in the absence of relevant sensory feedback but Wilson and Wyman (1965) also varied the timing of electrical stimulation of wing proprioceptors and found that the temporal phasing of the output was unchanged although the overall frequency of the wing movements gradually changed as if the input were being integrated. Wilson concluded that there is a central programme for wing movement in the locust but that output does change as a result of input although after a considerable time lag. Wilson suggests that the specific output pattern is genetically predetermined but that it can be modified to meet current needs.

The relevance of these studies to human control of learned movements is small. Species specific behaviour patterns which are relatively inflexible do not appear in man - even basic locomotion must be learnt. A genetic programme for the control of locusts wings is an indication of the rigid and unadaptable nature of the locust's nervous system and does not mean that a learned response in man has an acquired programme which works in the same way.

Of more direct relevance to the question of the use of sensory feedback by humans are the studies of Taub and Berman (1968) in which monkeys were surgically deafferented. Mott and Sherrington (1895) had reported that rhesus monkeys with one forelimb deafferented did not use that limb for walking or climbing and concluded that kinaesthetic feedback was necessary for movement. However Taub and Berman (1968) found that if both forelimbs were deafferented the monkey used both of them relatively accurately, even when blindfolded.

The ability of these monkeys to learn to re-use a limb with the loss of all peripheral feedback indicates that a motor programme with a central feedback loop operates. However this relearning occurs whether or not the monkey had reached mature motor patterns before surgery (Taub, Perrella and Barro 1973). Taub et al. deafferented monkeys on the day of birth. Ambulation, climbing, and reaching towards objects developed spontaneously, although they were retarded by up to two weeks. Monkeys deafferented and blinded developed crude ambulation and were shaped to make discrete extensions of the arm towards the front and to co-ordinate hand to mouth movements. Taub et al. conclude that although a great deal of motor learning takes place in infancy "the basic programs for many patterns of movement do seem to be present in the primate central nervous system at birth" (p. 960). Some genetic preprogramming may be present in the human infant, perhaps even enough for crude simple movements, but this is again different from the question of whether or not humans use preprogramming to operate learned responses. However, the finding that blind deafferented monkeys can be trained to make movements indicates that although the general ability may be genetically determined a specific gesture such as moving the hand to the mouth can be taught using a reward (or knowledge of results) system. That is, motor commands can be altered using knowledge of results without any sensory feedback.

Konorski (1967) established operant responses in dogs, rats and cats with deafferented limbs. He reported that such responses were clumsier than those made with normal limbs. The pattern of movements was correct but the spatial location of a movement sequence was not. Again, rewards operating as knowledge of result of action allow learning without kinaesthetic feedback although precision of movement may be dependent on such feedback.

The removal of kinaesthetic information feedback has been attempted in normal humans by the use of a nerve compression block which eliminates sensory feedback from the arm. This technique involves the application of a pressure cuff around the arm just above the elbow, which cuts off the blood supply. The ensuing lack of oxygen anaesthetises the afferent fibres and Laszlo (1966) and Goodwin, McCloskey, and Matthews (1972) indicate that this happens before the anaesthetisation of the efferent fibres. Laszlo and Bairstow (1971) report that there is an interval of 5-10 minutes during which the subject can make movements but has no feeling in the lower arm if the cuff is applied above the elbow. Tasks are very short and involve only finger or wrist movements, they are performed as soon as sensitivity to active and passive movements has been lost while subjects remain able to grip the experimenter's hand. Goodwin et al. report that the period for which motor power remains may be only two or three minutes.

Laszlo (1966) instructed subjects to tap a morse key "as fast as possible" and found that when the nerve compression block was applied the rate of tapping decreased immediately but increased over successive test trials. A further study (Laszlo 1967) found improvement over nine testing trials spaced one week apart. This improvement was with auditory and visual feedback available. When these were removed by blindfold and white noise the rate of tapping decreased markedly. Laszlo and Manning (1970) investigated the effects of various types of training on subsequent performance without feedback. These were different amounts of practice with full visual, auditory and kinaesthetic feedback, and a writing task.

Performance under conditions of no feedback was not improved by previous practice with all feedback channels available, i.e. the standard did not appear to be strengthened by this practice. Laszlo and Manning conclude that performance can improve without peripheral feedback but that when these loops are present subjects use all available information, they do not rely on central programming alone.

A slightly more complicated task was used by Laszlo and Bairstow (1971a) under the same compression block conditions. They investigated the skill of writing with the index finger, a task designed to be both familiar and novel in that the standard for writing is presumably well established while the use of the index finger would require unfamiliar movements. The accuracy of writing was considerably impaired under nerve block conditions but the rate of writing increased over the testing trials. Laszlo and Bairstow interpret this as showing that peripheral feedback is necessary for the control of novel and accurate movement. Subjects could approximate to the shape of the letter required but found it difficult to position the letter on the page and to cross 'i's and dot 't's. This is similar to the clumsiness reported by Konorski (1967) in the operant responses of deafferented animals. Further support comes from the results of a circle drawing experiment performed by Laszlo, Shamoon and Sanson-Fisher (1969), in which rate of performance increased with practice but accuracy did not.

These studies by Laszlo and her colleagues indicate that for a simple task, in which rate of performing is important, rate can be improved in the absence of sensory, especially kinaesthetic, feedback. For more complicated tasks where accuracy and control are required peripheral feedback is necessary for competent performance. This position is similar to that of Keele (1973) who suggests that motor programmes control gross motor patterns but that peripheral feedback is used to give information about starting positions, to monitor performance and to make fine adjustments. If a motor programme is conceived of as such a general pattern for a skilled act, then the control which makes an act appear skilled (i.e. accurate), co-ordinated and possibly fast, may be due to peripheral feedback.

The task most used in these studies is simple tapping. This may not be the task most likely to give illuminating results for skilled performance as it is difficult to see how sensory feedback could be used to control a task in which extent and direction of movement are not important, only rate. The improvement in rate shown may be an indication that subjects are becoming more familiar with the task under abnormal (and sometimes painful) conditions. In tasks in which co-ordination and spatial skill is important (such as circle drawing) no improvement in performance was found, even with visual feedback. (Laszlo et al. 1969). This lack of improvement with visual feedback should not have been found had an open loop motor programme been operating, that is, one amenable only to knowledge of results for error correction. On these grounds alone it is not clear that a motor programme which can operate in the absence of sensory feedback has been demonstrated.

The value of pressure cuff studies depends on the accuracy of the claims that motor outflow is not impaired when sensory afferents are eliminated. Some criticisms of the technique have been put forward which throw doubt on all conclusions drawn from these studies (Keele 1968, Kelso, Stelmach and Wanamaker 1974). Kelso et al.(1974) accept that the nerve compression block technique would be a very useful way of distinguishing between outflow and inflow models of control but they question the basic assumption that efferent fibres are not affected until some time later than afferent fibres. They investigated the motor nerve conduction velocity and the amplitude of the evoked action potential under nerve block conditions and found that the nerve conduction velocity for the axilla to the elbow nerve segment in both ulnar and median nerves showed progressive decrements as the duration of the conduction block increased. A decrement was also shown between the elbow and the wrist. The evoked action potential also changed under nerve block conditions. The height of the evoked response dropped by 55% for the median nerve by the 19th minute under block conditions and by 95% by the 25th minute. As the sensory end points for touch and kinaesthesis were 22.6 minutes and 24.9 minutes respectively, the authors suggest that motor impairment was well advanced before subjects peformed the tapping tasks required. The authors argue that "since neural transmission has been altered the characteristics of the skill to be performed have changed" (p.181). Both central and peripheral theories would predict poor performance under these conditions so that the nerve compression block technique may not be adequate for distinguishing between the two approaches.

1.3 Sense of Effort

The subjective experience of performing motor acts without kinaesthetic feedback is recognised by Merton (1964) as a "sense of effort". According to Merton, the knowledge of active movements is based on efferent commands, not feedback, so subjects who are prevented from completing a movement under conditions of no feedback believe that they have finished it. Merton anaesthetised the thumb and found that a blindforded subject could make very accurate thumb movements, but if the thumb were held it was believed that the intended movement had been made. Provins (1958) obtained similar results by injecting the index finger with local anaesthetic near the metacarpo-phalangeal joint. Passive movements were not detected but the rate of flexion and extension of the tip of the finger was little impaired. Both these studies have been criticised by Goodwin, McCloskey and Matthews (1972) on the basis that their sensory tests were not stringent enough. Provins tested kinaesthesis using one slow angular movement so that his findings cannot be generalised to rapid movements and Merton gives no quantitative results but simply states that the top of the thumb was "quite insensitive to passive movements of whatever range or rapidity" (p.394). Goodwin et al. attempted to replicate Merton's findings and found that subjects with anoxic hands could detect when the course of a large movement had been interrupted. The difference may be attributed to the angle of movement made by the subject - Merton' used 20^{o} while Goodwin et al. used 90^{o}.

If subjects can use a corollary discharge which provides efferent information for comparison with a standard, it should be possible for a movement made with one hand to be duplicated by the other, even if feedback were not available. Goodwin et al. (1972) investigated this using a pressure cuff to eliminate afferent feedback from one hand, the movements of which were to be duplicated by the other hand. As anoxia progressed the subjects were first unable to detect the movement they had made and then unable to make the movement at all. However if a corollary discharge existed which represented the intended movement then even when one hand was paralysed subjects should have been able to duplicate movements they were unable to make. This they could not do.

Laszlo (1966) has observed that subjects under nerve compression block conditions were able to make movements but could not say exactly when they had done so. However Laszlo and Manning (1970) found that some subjects reported the number of 'tapping efforts' but did not know how many actual taps they had made. One such subject reported 77 tapping efforts in a trial in which he made 75 taps. This provides some evidence for a sense of effort, but may relate to an isolated incident as no overall data is given. It should be possible to study the sense of effort in a tapping task, as motor impairment is probably not severe enough to prevent this. If impairment is severe enough to prevent all movement, the duplication technique used by Goodwin et al. (1972) could be useful.

1.4 Active and Passive Movements

Many of these studies have used subjects' inability to detect passive movement as evidence that neither a central copy nor kinaesthetic feedback was operating. Active movements tend to be duplicated more accurately than passive ones (Paillard and Brouchon 1968, Martenuik et al. 1972, Martenuik and Roy 1972). This has been attributed by Paillard and Brouchon (1968), and Jones (1972), to the presence of an efference copy for an active movement but none for a passive movement, because if a movement is active and voluntary, then the course and end of it will be known in advance, which is not the case for a passive movement. Paillard and Brouchon (1968) suggest that similar results would be found if the muscle spindles were available to provide afferent kinaesthetic information during active movement. Experiments by Goodwin, McCloskey and Matthews (1972) show that afferent information is available from the muscle spindles.

Goodwin et al. (1972) distorted the position sense in the arm by vibrating the biceps or triceps muscle. This gave rise to a subjective feeling of movement suggesting that discharges of the muscle spindles were interpreted as if they were due to stretch. In addition Howard and Templeton (1968) suggest that it is unlikely that the activity of muscle spindles is the same under both types of movement as gamma afferent fibres which prime the muscle spindle endings to be sensitive to differences in the length of the intrafusal and extrafusal fibres, operate under conditions of active rather than passive movement. This differential availability of afferent information confuses the issue of motor outflow control of active rather than passive movement.

Physiological studies of active and passive movement characteristics do not confirm the expectation that passive movement is less accurately duplicated than active movement because of the lack of efference copy. This is mainly because afferent feedback can give information regarding movement in the absence of an efference copy and becuase the feedback itself may fulfil different functions in the two types of movement.

Performance studies of active and passive movement also provide confusing results. Jones (1972), holding the view that active movements use a motor programme while both passive and restrained movements do not, investigated the accuracy of reproduction of movements made in each of these ways. He found that both passive and restrained movements (those made to a stop) gave less accurate reproduction than did active movement. However as Gundry (1975) has pointed out, the test movements were all voluntary and both active and restrained movements subjects had a pattern of commands available from the previous movement. It is not possible to test for the use of a motor programme in voluntary rather than restrained movement. After a movement to a stop has been made many times accurate retention of the distance moved can be shown when the stop is removed. (Holding and Macrae 1964).

There is some indication that passive movement may differ from active movement in motor memory rather as distance cues differ from location ones. Location cues are eliminated if subjects are required to duplicate a movement extent, starting the reproduction from a different position than the criterion. Distance cues are removed if the end position of the criterion movement, rather than its extent, is the target. Martenuik (1973) found some similarity in the differences between retention of active and passive movements and those between retention in distance and location conditions. Location cues produce much less error than do distance cues and it has been found that an interpolated information processing task interfered with location cues while distance cues decayed over time (Laabs 1973, Keele and Ells 1972). Laabs (1973) suggested that location and distance cues are differentially coded; location is coded centrally and therefore in need of rehearsal and distance kinaesthetically in a decaying trace. Martenuik (1973) does not find a spontaneous decay with distance information but he uses a mental rehearsal interval rather than a rest interval between criterion and reproduction movements. This conscious mental rehearsal may not fulfil the functions of rest for either of the two conditions. If mental rehearsal is a form of practice in that innervation of the relevant muscles occurs, although not sufficient to produce movement (Richardson 1967), then this could have the effect of an interpolated task, especially if the movement were rehearsed wrongly. Posner (1967) found that there were different memory codes for visual and kinaesthetic information suggesting that it was visual information which was centrally coded while kinaesthetic coding was peripheral and subject to decay. If this is taken together with the findings of Laabs (1973) and Keele and Ells (1972) it can be suggested that visual feedback gives knowledge of position which can be rehearsed, while the kinaesthetic cues, which may mediate distance, decay.

It would appear that location cues should be available from passive movement while distance is not, yet the comparatively useless distance cues (Stelmach 1974) are treated like passive movement. Martenuik (1973) has suggested that location and distance cues are differentially represented in memory initially, as are those from active and passive movements. If this were so passive movement should be represented in memory by position cues and recalled well. Martenuik (1973) uses an active distance condition which according to Jones (1972) should have been controlled by a motor programme and therefore be recalled well after an unfilled interval but Martenuik does not report the results of each group in his experiment, only of each main factor (active-passive and distance-location) and the results are therefore confounded.

Gundry (1975) has suggested that passive movements which show retention characteristics similar to distance cues may be fast and smooth and therefore have yielded distance information as a function of rate and time of movement. Jones' (1974) hypothesis that a motor programme controlled active movement would suffer interference after an interpolated task while a passive or constrained movement would show decay, has not been investigated with distance and location cues separately. Of the short term motor memory studies most have used a constrained criterion movement (i.e. to a stop) and have shown differences in coding and or retention of distance and location (Keele and Ells 1972, Laabs 1973, Roy and Martenuik 1974). Only Martenuik (1973) used an active criterion movement and although he also controlled distance and location cues he does not report these results as has been mentioned above. Jones' (1974) expectation that motor programmes should show interference from an interpolated non-motor task may be an idiosyncratic view of motor programmes. Indeed the short term memory paradigm used in these active-passive studies may not be applicable to the control of a well learned skilled act in which the role of a motor programme may be to organise and time sequential output without demanding attention (Keele 1973). Performance studies of active and passive movements do not show that central control operates because of the nature of the movement rather than because there are different memory codes for different types of feedback.

1.5 Rapid Movements

The ability to make rapid "ballistic" movements has often been assumed to require motor programming control. In such movements there is thought to be no possibility of guidance during execution because the movements are too fast. In judging whether a fast response is preprogrammed or not, the speed of the movement is typically compared with the kinaesthetic reaction time. If the movement speed is less than, or about the same as, the reaction time no kinaesthetic error correction can be made. The value of the kinaesthetic reaction time is usually taken as around 120 milliseconds based on the work of Chernikoff and Taylor (1952) who measured the time taken to return the extended arm to horizontal after it had been dropped and found an average time of 120 msecs. Gibbs (1965) considers that the kinaesthetic reaction time is 100msecs, based on what he calls "the latency in the motor-proprioceptive circle of nerves" (p.175). This 100 msecs time for processing kinaesthetic information is also arrived at by Stetsom and McDill (1923) and by Ruch (1951). Gibbs (1965) reports a correction time of 110 msecs in a step input tracking task which is similar to this figure.

The much quoted example of the skilled musician who can respond too quickly for kinaesthetic feedback to be controlling each movement was used by Lashley and has "been visible for 20 years as a proof of a motor programme concept and it has been curiously resistant to experimental test for as long" (Adams 1971 p. 142). The much more testable task of typing also has very fast movements and is very suitable for investigating this point. Hershman and Hillix (1964) state that a fast touch typist can make one stroke per 100 msecs although they themselves report a fast typist with a rate of one stroke per 150 msecs while typing continuous prose. Shafer (1973) describes the performance of a fast typist working at a maximum rate of 9 strokes per second or one stroke per 111 msecs. He also found that on the common three letter words "and" and "the" the subject averaged 90 msecs per letter. Other three letter words averaged 115 msecs and the increased speed was not found when the short words were part of other words such as "there". This suggests that these words are run off as an "arpeggio of fast movements" (page 443) in which the motor act is not three separate strokes but the typing of the complete word.

Such speeds of typing would seem to indicate that the time taken to initiate and execute a correction would be longer than the movement time. Chernikiff and Taylor (1952) and Poulton (1974) have suggested that the control of movements on the basis of kinaesthetic error feedback would require choice reaction time of a high order. The subject would have to choose whether an error existed or not and then to choose the direction of correction to be made. The original study of Chernikoff and Taylor required only that movement be detected and reversed which is a simpler task. Fast typists do detect a large percentage of their errors without terminal visual feedback (Shafer 1973, Shafer and Hardwick 1969). This is most often shown by a change in the time taken to type the next letter. This error detection loop however, could be kinaesthetic or central, either feedback or efference copy proving wrong in comparison with a standard.

Some evidence for the central control of very fast movement correction has been given by studies of step input tracking (Gibbs 1965, Higgins and Angel 1970, Megaw 1972). In Megaw's studies the subject was required to move a lever so that a pointer was aligned as quickly as possible with the most recently illuminated of 5 or 3 neon lights. Trials were either continuous or followed a warming signal. When stimuli were presented continuously at two second intervals and the choice was either a movement to the right or one to the left (two choice R.T.) an overall correction R.T. of 64 msecs. was found based on change of acceleration. Gibbs, (1965), and Higgins and Angel (1970), found error correction times larger than this but used displacement and velocity measures respectively. Megaw considers that these fast corrections are achieved by modifying the pattern of ongoing activity and could be due to central rather than kinaesthetic feedback. The subject has to detect the movement error and simply reverse it so that there is no uncertainty of correction and the fact that the stimuli are presented at regular intervals may mean that movement occurs which is checked and corrected as part of the programme. The 64 msec reaction time is therefore not interpreted by Megaw as a kinaesthetic reaction time because central control operated. The initial movement was made on a command which included the possibility of the correction. In Chernikoff and Taylor's paradigm, movement had first to be detected and then corrected. The 64 msec correction time may be more indicative of minimum correction time when the direction of correction is known in advance, and it may not be controlled in the same way as the 120 msec time. The passive initiation of the movement used by Chernikoff and Taylor (1952) means that the reaction time must be due to the time taken to perceive movement and this is not the case with the step input tracking studies. If the subject initiates and corrects the movement it is impossible to say whether the control is central or peripheral and as the correction time found is extremely fast this could be due to the simple nature of the choice required after a fixed interval, or to a motor programme, or to an interaction of the two. The role of kinaesthesis is still not clear and the time given by Chernikoff and Taylor for kinaesthetic reaction time is not disproved by step input tracking studies.

The typist who works at approximately one stroke per 100 msecs initiates each movement and therefore has efferent information available, however, if an error is made, the choice for correction is not easy. Eight fingers are used and each finger controls up to 6 keys so to detect which finger is in error and on which key is a complicated process whatever sort of feedback loop is used. It is most probable, given the complicated nature of the task and the speed at which it can be performed, that kinaesthetic feedback is not used to detect error.

Schmidt (1972) and Schmidt and Russell (1972) have investigated the relationship between the movement time of a response and the degree of preprogramming involved. They calculate the amount of preprogramming from temporal measures taken in a receptor anticipation task (Poulton 1957). The temporal discrepancy of the subject reaching his target when the target reaches its final position (algebraic error), the duration of the subject's movement, and the interval between the subjects initiation of the movement and the arrival of the target at its final position (starting time), are the three measures involved. When a subject makes no error he has chosen a correct starting time and made the movement within that time so that the starting time minus movement time equals zero. The index of preprogramming or IP is defined as the within S correlation between algebraic error and starting time. Using this method it was found that responses which involved a movement time of 150 msecs or less were completely preprogrammed, that is, algebraic error and the time between the initiation of the movement and the arrival of the target at its final position were very highly correlated. This again indicates that fast movements are not under the control of peripheral feedback.

Klapp (1975), arguing that for preprogrammed movements the preprogramming must occur during the reaction time, showed that for very short movements (2 mm) the reaction time increases as the size of the target decreases i.e. the increased complexity of the task affects the RT for very short movements more than for long movements in which the typical initial fast movement followed by a slower positioning movement is found. (Peters and Wenborne 1936, Annett, Golby and Kay 1958). Klapp found that movement time increased with increasing movement length and decreasing target diameter except for the 2 mm movement which showed the same movement time for all target sizes larger than 8mm diameter. This is a departure from Fitts' law (Fitts 1954) which states that movement time is a function of amplitude of movement and target size. Fitts' law appears not to hold for very short distances (Keele 1968). The role of preprogramming would have been clearer had movement time for these short distances remained the same while reaction time increased with a smaller target. However, as precision of response causes an increase in both it is difficult to rule out the use of feedback control.

Rather than showing a complete preprogramming for short movements Klapp's work suggests that the degree of preprogramming for short movements is much greater than for longer ones but that some feedback control may operate. Only very fast movements can be said to be controlled centrally and preprogrammed before execution so that no stimulation arising during the execution can alter the course of the movement. Even very short movements which are not faster than 200 msecs. may be affected by some response produced feedback. This suggests that skilled activities which appear to operate in a ballistic fashion, such as a practised golf swing, may be pre-programmed.

The use of visual feedback for the control of aiming has been demonstrated by Keele and Posner (1968). They showed that movements with an average time of 190 msecs were equally accurate whether the light remained on or was switched off immediately the movement began. Movement times of 260 msecs or over showed a decrease in accuracy without visual information. Similar times were reported by Vince (1948) whose subjects made rapid movements closing their eyes after each movement had begun. This technique however meant that subjects were blinking rapidly and Poulton and Gregory (1952) have shown that intentional blinking 50 times per minute disrupts tracking performance more than having the track blanked out for an equal number of times.

Some experiments have used the movement time of 150 msecs suggested by Schmidt and Russell (1972) to elicit movements which are not controlled by ongoing feedback (Roy and Martenuik 1974, Schmidt and Wrisberg 1972, Schmidt and White 1972, Newell 1974, Newell and Chew 1974). When the accuracy of end position is the dependent variable then error detection and correction would require at least two decisions and even if the kinaesthetic RT were 100 msecs for a simple reaction it would be greater than that in this case.

1.6 Adams' (1971) Two Trace Theory

Experiments on ballistic movements are not all interpreted in favour of a central rather than a sensory error detection loop for movement control. In Adams' two trace theory the memory trace, acting as a modest motor programme, initiates the movement. The perceptual trace, which is built up from the sensory consequences of previous movements and is a modal sensory image, detects error in the absence of knowledge of results by comparing the actual sensory consequences with the expected ones. In Adams' (1971) original formulation the theory was applied to graded movements and sensory feedback included proprioception, audition, vision, and touch. The perceptual trace is similar to the idea of an image or trace such as was suggested by James (1890), Sokolov (1969) and Bernstein (1967). In the early stage of learning (the verbal-motor stage) Adams suggests that KR is used to alter subsequent responses and that the perceptual trace is used in conjunction with this knowledge of results. When learning is well advanced and the error reported by the KR has been very small for some time the theory proposes that KR becomes unnecessary and the subject can match up the strong perceptual trace built up from previous trials with the feedback from the actual response and so 'knows' that the response is correct.

The memory trace in Adams' theory elects and initiates the response and is also strengthened as a result of practice. It is a necessary concept given that the perceptual trace is feedback based and feedback occurs only after a response has begun. The memory trace which must arise initially from task instructions and general information about the task may be seen as feed forward in that it directs what is produced (Bruner 1970). Adams suggests that recall of a response is controlled by the memory trace while recognition is controlled by the perceptual trace. As both traces develop during practice it is clear that in the motor stage an accurate memory trace must exist and it is not clear why this could not control performance in the absence of KR and even of sensory feedback in the way in which a motor programme would do. If performance improves without knowledge of results then some other error detection loop is operating but this need not necessarily be a sensory feedback loop - a central loop as proposed by Laszlo and Bairstow (1972) could perform the same function. However, if performance of a well learned task could be disrupted by changing the sensory feedback then neither an open loop motor programme nor a central efference copy could be controlling the movement. Adams suggests that this could be investigated by manipulating visual, kinaesthetic and auditory stimuli associated with the movement.

In addition to improvement in accuracy over time without KR as evidence of a perceptual trace, subjects' subjective estimates of error and confidence in their performance should be related to the strength of the perceptual trace. Subjective error should be very much lower than objective error as the subject is using the best information available to him in an attempt to null error from the previous trial. (Adams 1971, Adams and Goetz 1972). This is extended by Schmidt and White (1972) who hypothesised that increased confidence would reflect a stronger perceptual trace, while the discrepancy between objective and subjective errors should increase as the trace developed. None of these confidence or subjective error ratings would be unexpected if a central feedback loop were providing error detection rather than a sensory one, i.e. providing an accurate internal reference were set up any control loop would produce confidence.

Adams, Goetz and Marshall (1972), using a position learning task in which the subject was required to learn to move a slider without time constraints and with knowledge of results, allowed some subjects visual, auditory, and increased proprioceptive feedback (provided by spring tension in the slider). These subjects were considered as having augmented feedback while those who had no visual or auditory feedback and for whom the increased tension on the slider was removed were considered to have minimal feedback. The minimal feedback condition made subjects perform less well in practice but during KR withdrawal trials the greatest decrement was shown by those who changed from augmented to minimal feedback. These subjects were actually worse on test than at the start of acquisition. Subjects with 150 trials under augmented feedback conditions with KR continued to perform accurately if augmented feedback was still available when KR was removed. Subjects' estimated error was found to be much smaller than their actual error. Throughout the experiment estimated error was smaller for groups with augmented feedback than it was for those with minimal feedback. This is seen as evidence for a stronger perceptual trace developing with augmented feedback.

When mean error scores in this experiment were algebraic rather than absolute no significant effects were found at all. As the average error in test appears to vary from approximately an eighth to one and a half inches this indicates that subjects who learned or were tested with minimal feedback over and undershot the target so that their signed mean error was the same as for the continuously augmented feedback group. Minimal feedback during practice may lead to a much weaker trace so that an accurate modal value may not develop. Had a motor programme been operating the command would have been changed due to KR and a change in sensory feedback would not have affected performance.

The creation of a stronger error detection trace with augmented feedback was also shown by Adams and Goetz (1973) who used fewer trials (2 or 10 instead of 15 or 150 as in Adams et al. 1972) but found that error in movement to a stop could be detected and corrected after 10 trials with augmented feedback but that no improvement was found over practice when feedback was minimal.

Adams and Goetz (1973) suggest that "it would seem that practice improves performance as long as a feedback channel codes informatively with respect to significant features of the response; otherwise not" (p.223). They state that practice can only interact with such informative feedback and by a somewhat circular argument suggest that in their experiment augmented feedback was informative because it did so interact with practice.

It is noticeable that this theory is not one of kinaesthetic feedback control of movements but of on-going feedback control from any modality whatsoever. Nevertheless Adams and Goetz found that subjects without vision, audition or augmented kinaesthetic feedback were able to distinguish between a criterion movement and a fairly large error movement, even although this did not improve from 2 to 10 trials. This indicates that either information from joint receptors can be used to build a trace which may be very slow to develop so that 10 trials are not enough or that a central feedback loop is performing the same function. No one denies that the visual modality is a very dominant one (Connolly 1970, Fitts 1951, Rock 1966, and Rock and Harris 1967) and these experiments confirm this but have little to say about the formation of kinaesthetic control in the later stages of a skill when visual control is presumed to be delegated. If visual feedback is a performance rather than a learning cue then it would be expected that subjects who learned with such feedback would find the task difficult when the feedback was removed. These experiments do suggest that although an open loop motor programme may be used when there is no alternative (Lashley 1917) such control cannot equal the optimum performance shown when many modalities contribute to information about the task.

Other studies of Adams' theory have attempted to separate the improvement in the memory and perceptual traces by using a ballistic movement (Schmidt and White 1972, Schmidt and Wrisberg 1973, Newell 1974 etc.) Schmidt and White (1972) suggest that the memory trace initiates and governs a ballistic response because feedback from the movement will not be received in time to do so.

However, they then consider that error detection will take place after the response when the perceptual trace is compared with the feedback which actually arose from the movement. This is a closed loop approach to ballistic movements which differs only from those already mentioned by the use of sensory information for error detection after the event.

Schmidt and White (1972), using a 150 msec trial, found no decrement in performance on KR withdrawal after 10 trials with KR but that error did increase without KR if it was removed early enough (Bilodeau, Bilodeau and Schumsky 1959). Newell and Chew (1974) found that performance asymtoted after 10 KR trials of a similar task but deteriorated after KR was withdrawn at this stage. However they used 13 year old boys as subjects and Whiting and Cockerill (1972) report differences between children under thirteen and adults for;such a simple task so this may not be a comparable result.

No evidence of an error detection mechanism is given by Schmidt and White (1972) although they interpret the results as showing improvement when KR is removed. Had they hypothesised that performance did not improve when KR was withdrawn the results would also support this. A motor programme would account for these results as well as a perceptual trace does.

Subjective measures provide little evidence for the theory in this study. Objective and subjective error differences decreased over practice trials while the correlation between the two increased. Newell (1974) also found this and but showed no difference in correlation between objective and subjective error for subjects with and without KR for 77 trials. Newell suggests that repeating a task leads subjects to perform about their own criterion for the task and enables them to estimate error about that criterion even although they receive no knowledge of results and cannot know how long their movement actually is. Seashore and Bavelas (1941) came to a similar conclusion after re-analysing Thorndike's line drawing experiment. They showed that subjects who received no knowledge of results made very consistent estimations of the length of a line although they were not very accurate with respect to the target length.

Subjective measures are often difficult to interpret. Schmidt and White report that objective error confidence increased from about '2' (fairly sure it was not) to about '3' (don't know). Whether 'don't know' indicates more confidence than anything else is a moot point even if it was presented as the central point on a scale. In addition the subject who is fairly sure his response was not close to the target is in fact displaying a better ability to judge error than does one who cannot decide whether it was or not. Newell (1974) also makes some questionable interpretations of subjective data. He reports that KR subjects halved their error estimate on the second trial and considers this as evidence of the power of the perceptual trace to detect error after only one trial. Adams (1971) would appear to be in agreement with this. However, the actual error made on this trial was much larger than that on the first trial so it is more likely that the error estimate reduction was due to the extra information about the task given by one KR trial. Most people have little idea how long 150 msecs ought to be and one KR trial would have removed a great deal of uncertainty from the situation. Actual and estimate error scores for the first two trials are highly negatively correlated indicating that the second error estimate was not an accurate detection of the error made.

If a perceptual trace is used to evaluate a ballistic response after its execution, the removal of feedback cues should mean that no further improvement in performance could take place. As the perceptual trace would not change the course of the movement, because of its speed, it would be used to change the programme selected for the next trial and if some feedback were removed no future correction could be made. Unless performance were completely open loop error in performance would be expected if the amount of feedback available from a ballistic task was reduced. However, Schmidt and Wrisberg (1973) investigating this, found no differences between feedback conditions with or without KR and no feedback by practice interaction of the type found by Adams and Goetz (1973). The task was a 200 msec slider movement and either vision or audition was removed. It was expected that performance would be best during learning when all feedback cues were present and that such learning would lead to better retention. Limited feedback tended to produce more variable responses but the amount of feedback did not affect either absolute or algebraic error. Again this may mean that the perceptual trace is not so strong in these conditions.

Newell and Chew (1974) also used a rapid timing task and trained and tested subjects under two conditions of visual feedback and two of auditory feedback (feedback present or absent in both modalities). They found no differences between groups in acquisition or withdrawal although there was a tendency for the group without vision and audition to perform less well. Subjects also gave subjective estimates of error after each trial and again these correlated highly with actual error. However subjective error did increase when KR was removed although this error did not increase over further no-KR trials.

All of these studies have been interpreted as supporting Adams' two trace theory, although Schmidt and Wrisberg were cautious about this. The results however, appear not to support the theory, in that manipulating feedback did not result in reliable increased error in performance or in subjective estimates. Performance of a ballistic task is independent of visual and auditory feedback (Keele and Posner 1968, Vince 1948, Whiting and Cockerill 1972) and the recognition of accurate performance is not differentially affected by removal of visual and auditory cues. Either control and error detection is mediated by kinaesthetic feedback which was not manipulated in these studies, or motor programme control does operate for fast responses. Error detection correlating with actual error would be found if a motor command were compared with a standard built up from KR of previous responses. Newell and Chew's finding that subjective error increases when KR is withdrawn, which they interpret as evidence for the two trace theory, could only occur if the memory trace had developed differentially from the perceptual trace. That is, the subject is able to perform the movement correctly (memory trace) but does not recognise it (perceptual trace).

The use of subjective error estimates to evaluate a perceptual trace has many difficulties. Adams' original position was that subjective confidence should always be high regardless of KR because the subject is eliminating error from the previous response on the grounds of the KR which followed it. "The expectation should be a considerable independence of objective error and judged error" (Adams 1971 p. 127). This is not found. On the other hand the considerable relationship which is found between these types of error indicates that under conditions of terminal KR subjects learn to correct their errors and to estimate their correctness.

In Newell and Chew's study the perceptual trace seems to recognise error but either it does not inform the memory trace of the correct extent of error or the memory trace is not competent to initiate a corrected movement. Error is detected (subjective error scores increase) but not nulled (actual error remains as it was).

On the other hand, if the subject were operating by comparing his last KR with his last motor command and subjective error estimate he could correct both equally on a subsequent trial. This explanation would cover the results for acquisition of the response and if the motor command had no internal feedback loop and was built up independently of the corrected subjective error then the results reported when KR was removed would be expected.

Ballistic movements have not been useful for substantiating Adams' theory, although for graded movements removal of all response-produced feedback does interfere with performance as hypothesised. The difference between these two types of movement was studied by Roy and Martenuik (1974) who attempted to differentiate between motor programming and proprioceptive feedback control using fast (150 msec) and slow (1000 msec) movements. Roy and Martenuik interpreted Adams' theory as emphasizing kinaesthetic feedback control as opposed to the preprogramming ideas of Keele (1968) and Laszlo and Manning (1971) and attempted to vary the amount of kinaesthetic information available from the task. They did this by training all subjects to move a slider to which a heavy flywheel was attached and then removed the flywheel for some subjects for test trials without KR. In addition they used a secondary task during test for some subjects in an attempt to remove all conscious monitoring of feedback cues. The secondary task required subjects to report the order of illumination of six lights, the report to be made after the movement was completed.

Algebraic or constant error was not affected by altering or interfering with the feedback from a fast response. For the slow response however subjects under-estimated when feedback was low, i.e. they took less than the required time. This would be predicted either by feedback theory or by response programming theory, as, if a subject begins to move a heavy slide 34 inches and finds it to be a light slide his motor command to exert so much force for so long will be wrong even if the command component which controls amount of muscle contraction and therefore of movement distance is correct. This has been noted by Howard (1970) although he gives no quantitative results of the study he mentions. The studies of Adams et al.(1972) and Adams and Goetz (1972) which altered the kinaesthetic characteristics of a task may also have changed the task itself in a similar fashion.

The error of movement time was reversed when the secondary task was performed with the 1000 msec movement and subjects over-estimated the time required. It might have been expected that if the conditions were of low feedback and no feedback they would have produced error in the same direction, however if the low feedback condition is in fact a different task this would not be the case. Gundry (1975) suggests that had Roy and Martenuik analysed their data using the same error term (the ANOVA within cell error) to test differences between means in an a posteriori multiple comparison they would have found an effect of changing from high to low feedback for both fast and slow groups. The variable error means for both fast and slow responses were the same under high and low feedback conditions and the magnitude change from high to low was also the same for fast and slow responses yet this produced a significant effect for the slow response and not for the fast response. If Gundry is correct in this then changing the characteristic of the response by removing a flywheel affects both fast and slow responses as would be expected.

The secondary task used is a fairly simple one but it may however disrupt the performance of a timed graded response rather than simply prevent the monitoring of kinaesthetic feedback. It may also have prevented verbal control of the response by counting or other strategies. For the ballistic movement however, the results of no change with the secondary task contradicts the suggestion of Schmidt and White, (1972) and Newell (1974) that the closed loop comparison occurs after a ballistic response, as this period was occupied by the secondary task which continued even when the movement was not being made.

It has already been stated that movements of around 150 msecs are not under the control of visual and auditory feedback. The main indication that they are not controlled by kinaesthetic feedback comes from Roy and Martenuik's dual task situation and brings in the question of attention to feedback as a determining factor. Responses of this duration appear not to be controlled by any feedback modality.

1.7 The Role of Sensory Feedback.

As there are at least two types of motor programme theory (Keele 1973, Jones 1974) there are also at least two types of feedback control theory. One is that all intrinsic feedback from a response whether extero- or intero-ceptive is used for error detection and correction, the other that in the absence of exteroceptive feedback kineasthesis gives sufficient information. Adams, Schmidt, Newell, and their co-workers all favour the all inclusive feedback control while Roy and Martenuik, and Laszlo and her co-workers are some of those who emphasize the kinaesthetic feedback loop. Jones' (1974) criticism of a feedback controlled model of skilled movements is actually an attack on the kinaesthetic feedback position. He stated that "unless it can be demonstrated in any experimental conditions that proprioceptive feedback about direction and extent of movement is necessary for movement control the more parsimonious outflow hypothesis provides a necessary and sufficient explanation of the phenomena". (p.41) Apart from the counter argument that the human nervous system is not renowned for parsimony in that as an organism with little adult behaviour evident at birth plasticity of the nervous system and the availability of highly adaptive levels of organisation are more noticeable, Jones' use of the word 'control' can only be referring to the crudest form possible. As has been noticed in the experiments with deafferented subjects and those using pressure cuffs, performance is possible but not competent without kinaesthetic feedback.

The position of Keele (1973) already referred to is very similar to that of Adams although Keele accepts motor programmes more explicitly than does Adams. If feedback is necessary to give information about the position of the limbs, i.e. organise a movement spatially, to monitor the learned task, and to give information necessary for learning (Keele, 1973) it would appear to have all the functions which Adams requires. If feedback monitors the progress of a motor programme it can presumably induce changes and therefore is necessary to competent adaptive performance of a well learned task.

Jones' dismissal of the role of kinaesthetic feedback is somewhat cursory. Fleishman and Rich (1963) used an individual difference approach to the roles of kinaesthesis and spatial organisation in a two hand co-ordination task. They divided subjects according to their ability to discriminate differences in weight (kinaesthetic sensitivity) and their ability to match pictures of the views of the horizon seen from a 'plane with pictures of the orientation of the 'plane which would allow such a view (spatial sensitivity), and found that performance on the two handed tracking task, while initially better for high as compared to low spatially sensitive subjects, was the same for both groups after approximately 40 four minute trials. On the other hand high and low kinaesthetically sensitive subjects began similarly but by the fortieth trial the more kinaesthetically sensitive subjects were performing better than the others. This is frequently taken to mean that the importance of kinaesthetic feedback increases as a skill becomes well learned.

Experiments which vary the type and variety of kinaesthetic information available have shown that different types of constrained movement differentially affect accuracy of retention (Bahrick, Bennett and Fitts 1955, Bahrick, Fitts and Schneider 1955, Notterman and Page 1963, Briggs, Fitts and Bahrick 1957, Weiss 1954, Gibbs 1954, North and Lominicki 1961). Many of these workers argue from the position that "accurate execution of movements depends upon proprioceptive information reaching the central nervous system" (Bahrick 1957 p. 324).

Gibbs (1954) found that pressure controls resulted in more accurate tracking than did amplitude controls and he argued that the resistance gives more kinaesthetic information to which the increased accuracy is due. Weiss (1954) found that for well practised subjects extent was a more useful cue than pressure in a positioning task and suggested that Gibbs' use of rate tracking allowed continuous visual feedback and that the movement of the control produced a velocity not a distance change. Distance change could be best made using an amplitude control. Bahrick et al.(1955) varied spring stiffness, damping or mass loading of a joystick control. They found that spring stiffness tended to improve positional accuracy but not significantly so, and that damping produced greater uniformity of movement speed while increased mass made velocity change more uniform. Bahrick, Bennett and Fitts (1955) gave more practice with the controls in order to show that spring loading cues could be used. They found that under optimum conditions of spring loading there were half as many positional errors as on a free moving control. All of these studies find that the response characteristics of a control influence the speed, accuracy and consistency with which a response can be made.

Notterman and Page (1962) compared tracking with a moveable control stick with various amounts of elasticity, damping, and inertia, with performance using an isometric control which gave a visual display similar to that produced by the control stick. Thus, subjects using both types of control had the same visual display but in one case kinaesthetic cues were available arising from movement as well as force while in the other they weren't. The moveable control gave better performance than the isometric one.

Russell and Martenuik (1974) consider that the kinaesthetic sense seems a modality ideally suited to provide sensory feedback and they attempted to determine the capacity of the system to transmit information. They argue, following Howard and Templeton (1966) that torque is an adequate stimulus for kinaesthesis. Equal discriminability scales were constructed for each subject along a torque continuum from 12,635 gms. per cm. to 202,160 gms. per cm. Subjects learned the sixteen stimulus categories and were then required to identify them. As the maximum amplitude of movement was 12 mm subtended by 0.29° of arc amplitude cues cannot have been very useful. The amount of information transmitted was based upon the number of stimulus categories available and the frequency with which each response category was used during the experiment. Information transmission for torque was less than for amplitude (Martenuik 1971) and a considerable degree of uncertainty was shown throughout the experiment. The highest rate of information transmission was 1.68 bits at 16 stimulus categories. However it is not totally clear that kinaesthetic information is being used to identify the movements. If, during the learning phase the motor output command rather than the feedback were 'tagged' with the resulting category information then similar results would be expected.

Jones (1974) considers that as most of the experiments on proprioception have used verbal KR during learning they have not shown that purely proprioceptive learning can occur. As "the crucial issue in the regulation of intentional action is the opportunity to compare what was intended with what in fact resulted, using the difference between the two as the basis of correction" (Bruner 1970, p. 67), it is difficult to see how a goal could be specified kinaesthetically. Visually guided movements which don't have a target specified require some additional augmented knowledge of results for learning to occur although without KR a movement once learned, can be maintained. Visually guided movements in which a goal is clear and for which there are no time constraints are accurate (Annett 1959) but knowledge of results is always present when the visually controlled movement finally leads to a visually detected nulling of error. Kinaesthesis cannot detect goal position and a current response position at the same time, as vision can and therefore in the early stages of learning no improvement would occur without augmented knowledge of results.

One of the many divisions of type of feedback which has been made is that into intrinsic and artificial (Holding 1965) or intrinsic and augmented (Annett 1969). Visual feedback can be both but this is much more difficult for kinaesthetic feedback. This may be one of the reasons why visual feedback is so powerful in controlling movements. In a visual aiming task the performance time is a function of accuracy and distance moved and this has been interpreted in feedback terms as the result of an initial fast movement and a slower homing movement near the target as was suggested by Woodworth (1899) (Welford 1968, Keele 1968). For non visual aiming at movement times of over 350 msecs, accuracy is a function of distance (Beggs, Andrew, Baker, Dove, Fairclough and Howarth 1972). Beggs et. al. consider that as vision is not operating then terminal accuracy depends on the initial impulse accuracy or motor outflow. However as subjects made 20 hits on each target and illumination of the apparatus followed each hit giving visual KR it could be that some kinaesthetic feedback control operated on later trials. This could not occur if no KR were allowed. Accuracy for non visual aiming was found to be less than for subjects aiming visually, as would be expected.

Although it has been commented that visual feedback may be detrimental to a well learned skill such as typing (Adams 1971) this is not a case in which intrinsic feedback is detrimental. The whole task of the skilled touch typist is to type while reading copy. Visual monitoring of the keys prevents smooth reading of copy and is therefore not intrinsic to the task. Visual information which is present during training may be detrimental if test performance is to depend on kinaesthetic information alone (Annett 1959, Karlin 1960). This in turn seems at odds with the belief that as a skill is automatised, control is delegated from vision to proprioception (Gibbs 1965, Mackintosh 1964, Connolly 1970). Fleishman and Rich (1963) concluded that vision is the most important channel early in learning while kinaesthesis is important later, and this supports the servo mechanism feedback control model of Fitts (1951, 1954). Mackintosh (1964) has proposed a similar view based on maze learning in the rat. He suggests that rats which have been overtrained to run to one of two goal boxes no longer use vision to control their choice of route but use proprioceptive feedback instead. This is based on the finding that after the goal box is changed the overtrained rat does not seem to see the first choice point where a change of direction would take him to the new goal. Similar kinaesthetic control mechanisms are used by MacFarlane (1930) to account for rats swimming to goals which they had been trained to run to. This is an odd use of kinaesthesis as a central organisation of the task seems more reasonable.

Chase et al. (1961) propose an alternative to this delegation hypothesis. Chase argues that the relative importance of the various channels depends on the type of activity being carried out and the modality used to learn that activity. Chase et al. using a key tapping task, masked auditory and proprioceptive feedback and removed visual and tactile feedback. The auditory and kinaesthetic masking conditions caused a decrease in rate and intensity of tapping while removal of visual and tactile cues did not. Unfortunately the masking as opposed to removal of cues makes it difficult to interpret this result but Chase et al., while believing that sensory information is critical for the learning initiation and control of voluntary motor activity - a position similar to that of Adams - conclude that the relative importance of one type of sensory feedback varies with the total pattern of sensory feedback of which it is a part.

It is obvious that in a task such as tracking, for which vision is an integral part, delegation of control is not possible. In car driving, part of which is a form of compensatory tracking, experienced drivers use peripheral vision more than do learners for information such as lane position while foveal vision is used for overall direction and scanning ahead (Rockwell 1972). When the task is well practised vision is still operative but tracking control has been delegated to peripheral vision so that a smaller demand may be made on conscious attention. Central vision may not be necessary in tracking tasks but visual information at some level is an intrinsic component of tracking.

Thorsheim, Houston and Badger (1974) trained subjects in a tracking task in which the track was lighted by flashes at frequencies ranging from 2 per second to 20 per second. All subjects were tested at a flash frequency of 10 per second and those subjects who had been trained with more light than this $\frac{2}{3}$ deteriorated more than those with a 10 per second training frequency.

Those trained with fewer than 10 flashes per second improved on test. This suggests that visual feedback leads to better performance of a tracking test as well as better learning.

One of the studies most often cited as evidence of motor programme control is that of Pew (1966). He used a compensatory tracking task and found that early in training subjects made a response, waited for feedback about the results of that response, and then made another movement to account for the inadequacies of the last one. Later in practice the pattern of responding changed. Some subjects allowed a slow drift off target which was periodically corrected using visual feedback while others used a 'modulation mode' in which the pattern of response was modulated as the response began to drift off target resulting in a slow drift to the other side of the line to be tracked. Thus after practice subjects seem to shift from visual control of individual movements to the use of visual feedback for the periodic correction of movements. However when subjects were responding interresponse intervals were lowest at 230 msecs. A pattern of movement which produced the modulation mode could have been controlled by kinaesthetic feedback. The open loop mode in which error built up until detected visually may not be different from early practice as regards visual error detection as the size of the accumulated error is similar to those found early in practice. If visual error detection is set at a certain value for error and such error does not occur often when the task is well practised and centrally organised then the type of response is actually similar with regard to error detection.

The differential coding of visual and kinaesthetic cues which has been mentioned in conjunction with memory for place and distance also contributes to the more powerful role of vision. This difference was suggested to Broadbent (1958) by the difference in degree of conscious awareness which accompanies processing of visual and kinaesthetic material. Posner (1967) considers that some of the difference may be due to the ways in which subjects normally handle information of different kinds as well as to differences which may exist at a more physiological level. People are not often asked to remember what a movement feels like but they are accustomed to measure distances by eye. Connolly and Jones (1970) have shown that visual and kinaesthetic information is coded differently based on their results from a cross modal matching task in which the length of lines were estimated. The stimuli were presented either visually or kinaesthetically and were matched in one of these two modes. Thus of four groups two were cross-modal and two in the same mode. Of the cross modal conditions kinaesthetic-visual was more accurate and less variable than visual-kinaesthetic for all age groups. The authors conclude that visual and kinaesthetic information are held in separate short term memory stores. However, the results also show that vision is more effective for judging a perceived distance than is kinaesthesis.

Klein and Posner (1974) required subjects to reproduce a single movement pattern which was presented either by passive movement of the subject's arm (kinaesthetic), or by visual presentation of a cursor moving on a screen. For some subjects both types of information were available but subjects were told to concentrate on one as that would be used in reproduction, while others were instructed to divide attention between the two input modalities and not informed as to which modality would be used for reproduction. It was concluded that visual reproductions were not affected by the presence of kinaesthetic information unless attention was divided between the two modalities, but that kinaesthetic information was affected by visual information whether or not subjects were trying to attend solely to the kinaesthetic input.

Attention to one modality rather than another was also found by Jordan (1972) in a task involving novice fencers who reacted faster when only kinaesthetic information was available than they did when both kinaesthetic and visual cues were present. In general, when conflicting cues are available from visual and other modalities subjective experience and objective performance appear to be under visual control (Rock and Harris 1967). However, when a simple movement is practiced repeatedly it is not clear that the same visual predominance is found.

1.8 Conclusion: Parsimony is not enough

The suggestion that since kinaesthesis cannot control movements as well as vision it is therefore not used in movement control at all does not appear to be justified. As a skilled movement becomes well learned and seems more automatic it may be that visual attention has been released by increasing the preprogrammed component of the movement, by switching visual control from foveal to peripheral vision, or allowing kinaesthetic feedback more importance. There is only very inconclusive evidence for the exclusive use of any of these mechanisms. Pew (1974) makes it clear that any model of voluntary motor activity is at best tentative. He considers that all levels of control, from efferent copy to knowledge of results, can be used if available, and puts forward a composite model which postulates a signal comparator in which the knowledge of goals, the image of sensory consequences, motor command feedback, sensory feedback, and knowledge of results, may all be compared in order to modify the "schema" or general information about the task (similar to the memory trace) and/or to modify the rules by which a schema instance is selected. The model is similar to those of Adams and Keele but is not rigid.

The idea of a schema accounts for the problem of how it is possible to make an accurate movement which has never been made before. The selection of a response from a range built up over time and experience of different external conditions and requirements enables selection of a unique response. Schmidt (1975) suggests that as the initial conditions and response specifications may never be exactly repeated then the response outcome and expected sensory consequences also cannot be based on an exact previous instance.

If a particular movement instance is selected from a schema or range then the expected sensory consequences will be those for the correct movement necessarily for the chosen movement, so subjective error labelling can occur. As has been noted this is not possible with a system such as that proposed by Adams (1971) in which the expected consequences are those of the actual movement carried out.

When an instance of the schema is selected based on information from the environment and previous feedback from schema execution this could be regarded as a motor programme, but this is heavily dependent on the organisation of the input from the stimulus conditions at the time, on which the goal or plan for the act is based.

Subjects may be able to perform simple motor acts without various forms of feedback but this does not mean that these types of feedback are not used when available. A rigid motor programming position, if this means that no feedback control is operating during continuous skilled activity, makes no allowance for the flexible nature of skill which enables us not only to walk without attending to our feet so that we seem preprogrammed but also to correct our pattern of walking for environmental conditions which require it. Pew's 1974 interpretation of his 1966 experiment is that subjects "were not ignoring feedback in order to impose a structure on their skill but rather were using feedback to monitor and control their performance at a level removed from the representation of individual key strokes". (p. 34) The level of control has shifted from individual key strokes but feedback is still used.

This is again the position of Keele (1973), who although credited with defining motor programmes nevertheless does not consider that programmed behaviour is un-monitored. Feedback is of great importance to the control of voluntary movement even although such movements are organised at a higher level and error may have to become quite large before the error signal from the monitoring senses is detected.

As a skilled task becomes highly over learned it can often be performed without conscious attention, for example, the act of changing gear while driving a car need not be attended to by the experienced driver, yet were the clutch pedal to stick as it was being depressed the feedback from the unexpected movement would attract attention. If such lack of attention is called a motor programme then it is simply another conceptual device for explaining skilled behaviour and means much the same as automaticity of, or lack of conscious attention to, a process. If the emphasis is placed on 'conscious' then we can understand a motor programme as one step in the hierarchical organisation of skill rather than as an inflexible, or relatively inflexible, habit chain.

There is little evidence which distinguishes between a central efferent feedback loop and a sensory feedback loop, except for very fast movements in which sensory feedback is not available in the studies which have been reviewed. Motor commands have been shown to control clumsy behaviour if used without feedback and feedback has not been shown to be irrelevant if available. Few of the studies have used a very overlearned task such as gives rise to the phenomena of automaticity in everyday life, such overlearning may be necessary for complete motor programme control to be demonstrated.

Chapter 2

The role of action information feedback in movement control.

2.1 Feedback: distinctions and definitions

Although the role of feedback in the control of a well learned skill may not be clear, feedback is extremely important during the acquisition of such a skill. The goal of the learner is to use all the information available about the task itself, and about his responses to it, in order to null error, and at this stage knowledge of results of action plays an important part. Bilodeau (1966) uses the term 'information feedback' (IF), which is defined as a function of the discrepancy between the response made and the goal. Response-produced feedback is not IF unless it can indicate such a discrepancy, and it is IF which is necessary for learning. In many cases IF is knowledge of results given by an experimenter or teacher, but if a target is clearly visible then subjects can use vision as a source of information feedback.

The distinction made earlier between intrinsic feedback, which is present in the task, and artificial feedback, which is added to the task during training (Holding 1965), is not the same as that made by Smith and Sussman (1969) between static and dynamic feedback. Static feedback occurs after the response, while dynamic occurs during the response as the sensory consequences of the movement. The position of Smith and Sussman is similar to that of Miller (1953), who made a distinction between action feedback, which is information about the changing state of the movement attempt, but which may not produce a permanent change, and learning feedback, which does produce a more or less permanent change. This split has been challenged by Annett and Kay (1957) on the grounds that it is unclear because "action and learning feedbacks may in some circumstances tend to adopt the functions of each other" (p. 75), so that the effect of removal of feedback can not be known before it is actually removed.

Annett and Kay (1957) have indicated the difficulty in defining types of feedback in terms of their consequences for learning but some confusion between the different feedback classifications still remains. Dynamic feedback which is continuous may also be artificial, that is, it may be removed from the training situation for test performance, while terminal feedback may also be intrinsic to the task. For example, aiming at a target is a task which depends on visual feedback, and this feedback is therefore both continuous and terminal, although it may be added to by an outside source. However, if the task is to learn to aim in order that the aiming may subsequently be performed without vision, then the same visual information, which guides the response during practice, becomes extrinsic and artificial. This means that in Adams' (1971) paradigm response-produced feedback may be either action or learning feedback although he insists that learning rather than performance alone is the function of all such information.

If visual information is present throughout training but is removed for test, then performance could be controlled by a motor programme built up during training, or other feedback systems, such as kinaesthesis or audition, might play a part in control of test performance. Such visual information will be referred to in the rest of this thesis as "action information feedback" (AIF), following Fox and Levy (1969).

2.2 Guidance

Annett (1969) has suggested that continuous visual feedback is a performance cue in that it guides the correct response if a target is available. However, this type of feedback also provides terminal information regarding the actual accuracy of the movement, and so can be seen as guidance in the same way as moving a subject's hand through a task constitutes guidance. Annett (1969) divides guidance methods of training into three main categories: forced response (putting the learner through the correct motions); verbal guidance (telling the learner what to do or prompting); and visual guidance (cueing or action feedback). Two of these depend on giving the subject experience of the response-produced feedback from the task, and this experience may provide a central standard for the task by making it clear what is required, or it may contribute to the building up of a sensory image with which further performance can be compared. Verbal guidance will also allow the subject experience of response-produced feedback, but the emphasis is placed on the understanding of the task.

The only type of concurrent augmented feedback which Annett excludes from 'guidance' is auditory feedback such as the additional auditory on-target signals used by Smode (1958). This is presumably because visual concurrent feedback, such as that used by Fox and Levy (1969) and Annett (1959), allows anticipation and therefore decreases error in performance, while auditory concurrent feedback may not do so. It is likely that an auditory cue may act as terminal feedback by signalling that the last movement made was or was not on target. Mechanical guidance on the other hand does not allow any error nulling procedures as the subject is moved through the correct motions without initiating anything.

2.3 Mechanical guidance

Studies of mechanical guidance have been reviewed by Holding

(1965) and Annett (1969). In general, the subject is required to move along a pre-ordained path which is later removed (Bilodeau and Bilodeau 1958, Holding 1959, Gordon, 1968). In one situation, hand-wheel cranking, (Lincoln 1956) mechanical guidance has taken the form of giving kinaesthetic error information. Subjects were required to learn the rate of movement of a handwheel and were given error information by holding on to the handle of the wheel while it was rotated at the correct speed, or at a speed equal to the error which they had made on the previous trial. The knowledge of error condition gave better learning and retention than experience of the actual speed required. It would appear from this that kinaesthetic information can be used to correct error if it is made available, and may be more useful than exposure to what the correct movement should feel like.

When a continuous visual cue was used to inform subjects of error in rate of responding in a cranking task (Lincoln 1954) performance during learning and relearning trials was accurate. However, when the visual cue was removed performance deteriorated, although there was some improvement over the initial trials, indicating that learning had occurred. Karlin (1960) considered that this cue was a source of action feedback and so could be expected to show the characteristics of accurate performance and poor retention. He also used a hand cranking task and gave subjects visual, kinaesthetic or auditory error signals which they aimed to turn off for accurate performance. Immediately after the extrinsic cues were removed the performance of the group given kinaesthetic error information was similar to that of a control group which had received verbal terminal KR, while both the visual and auditory groups were less accurate. However, the visual condition showed most accuracy on relearning and was worst in retention tests given after 24 hours. Karlin interpreted this to mean that visual cues are detrimental to the retention of a non-visual task and should therefore be avoided in a training programme. It is not clear why visual information should have this effect as two of the other methods of training also gave immediate information on error, unless vision operates in a manner different from that of the other senses. This implies that it is not the temporal characteristics of additional feedback which are most important but the perceptual system to which they apply.

It is possible that none of the feedback systems in Karlin's study were utilising action information feedback, if that is taken to be continuous extrinsic information which is removed for test, and which allows subjects to perform accurately during practice. All three feedback cues were error based, that is, the subject did not make a comparison between the feedback and a goal but was informed by the presence of the feedback that an error had occurred. Thus the presence of the feedback cue indicated that the previous movement had been wrong, i.e. terminal feedback was given for movement which was past, and subjects had to turn the error cue off. This procedure did not lead to very low errors in practice as would be expected from a guidance model of action feedback.

Studies of mechanical guidance do not allow error to occur and be corrected, but attempt to teach the subject by exposure to the correct response. Gordon (1969) raised the edges of a pursuit rotor track so that subjects could not commit large errors. Such subjects performed well in practice, but transfer to an unmarked track showed a decrement in performance. Armstrong (1970) guided subjects' arms through a tracking task so that they made very few errors in practice, but in test they showed poorer retention than any other training condition. Holding and Macrae (1964) performed one of the few studies of mechanical guidance of a discrete rather than a continuous task. In a modified line drawing task (moving a knob along a bar for four inches), subjects who held the knob passively while it was moved were much less accurate in test than those who had terminal KR or restricted guidance, i.e. movement to a stop.

The only study in which mechanical guidance has been found to be beneficial is one by Holding (1959), in which one guidance trial and one normal visual trial on a pursuit rotor was equal to two normal learning trials in producing accurate performance. The training period in this study was two minutes long and studies which find mechanical guidance to be a poor method of training have used longer training periods than this. Guidance may be useful early in training in making subjects aware of the characteristics of the task, but if used for extended periods it prevents subjects from creating their own control processes for carrying out the task.

Those interested in training per se, rather than in theories of movement control, appear to apply the name 'guidance' to what others have studied as passive movement. Mechanical guidance allows only passive learning, the subject does not initiate a response and therefore has no central command available to produce a correct movement when the guidance is removed. As most studies of passive movement (e.g. Jones 1973, Martenuik, 1973) have used discrete movements and short term memory they may not be directly comparable with guidance studies. However, the main purpose of such studies has been to show that giving subjects a feeling of the control to be used will enable them to know when they produce the correct feeling in further active trials. Such subjects presumably build up a central referent about the feel of the movement but not a central percept (memory trace, or motor programme), which would enable them to initiate the correct response as soon as the guidance was removed.

If motor programmes are built up during the learning of a task the evidence from mechanical guidance studies of poor retention when guidance is removed indicates that such programmes do not operate after passive learning. It is also possible that subjects who undergo such passive training are bored by the seeming ease of the task as there is no incentive for them - they cannot perform badly. The success of Holdings' (1959) one minute trial indicates that subjects remained interested over that period.

2.4 Visual feedback in continuous tasks

The type of visual guidance which is also action information feedback is usually augmented feedback, i.e. it is not intrinsic to the performance of the task when it has been learned. Tracking tasks, in which visual feedback is intrinsic and not a source of extra information, are not very suitable for studying the role of AIF, although they are used (Gordon, 1969, Robb 1968). Thorsheim et al. (1974) have shown that performance is better if more visual feedback is present during tracking, and Rockwell (1972) and Pew (1966) show that visual monitoring is necessary in a tracking task, although it may be peripheral and not central vision which is used.

The experiment carried out by Robb (1968) used a pursuit tracking display on which a light spot moved through a pattern which the subjects were required to learn. The subjects moved a control stick through the pattern, attempting to match a cursor with the target dot. This visual information was removed for test of whether or not subjects had learned the pattern. Robb claimed that "concurrent feedback was the most important variable for learning the movement pattern" (p.183), but her results do not support this, mainly because of methodological flaws in the study. The control group, which received terminal rather than concurrent feedback, could not see the screen but received a mean error score after each trial. This score was "proportional to the average difference between input and output without regard for sign, accumulated each trial" (p.178), which, presuming the movement was a complicated one, could not have been very informative. After each block of ten trials terminal-feedback subjects were also shown a plot of their last trial overlain with a plot of the target pattern. These two types of terminal feedback gave poor learning, but this is hardly surprising as the first measure is crude and the second infrequent.

Visual tracking in this study led to accurate practice performance which deteriorated markedly when vision was removed. On the first ten test trials the score for the visual group was worse than for the non-visual group in the first 10 learning trials, and although some improvement occurred in the next 30 test trials, there was little difference between these and the initial practice results. Robb reported that there was no difference in test performance between the no-vision learning condition, and the visual learning condition, which is surprising as the no-vision group were not as proficient as the other group by the end of 200 practice trials. In a separate treatment of position and timing errors visual practice was again shown to lead to decrement in test performance, although not more so than non-visual practice.

This study is not reported very clearly, and given the nature of the terminal training provided the conclusions drawn by the author cannot be substantiated. If anything, the results support the view that practice with a continuous visual feedback cue leads to good performance but poor learning.

The findings of Noble and Noble (1972) are slightly more conclusive. They trained subjects on a narrow pursuit rotor task which provided stylus guidance. In addition, subjects received visual feedback, auditory feedback, or visual plus auditory feedback while they performed the task. The performance and learning of these subjects was compared with that of subjects trained on a normal pursuit rotor task under visual feedback conditions. It was found that visual feedback was superior to auditory feedback (which had very little effect), while response guidance by means of a track was superior to the no guidance condition. However, Noble and Noble suggest that these findings indicate performance rather than learning effects, as performance altered dramatically each time the feedback conditions were changed. Although no data are presented which bear on this suggestion, there is some indication that in a continuous pursuit rotor task both continuous visual feedback and response guidance are performance rather than learning variables.

2.5 Visual feedback and discrete movements.

A frequently cited study of visual action information feedback (AIF) is that of Annett (1959). He used two tasks, plunger pressing and bar pressing, although only the results from the experiment which required the application of graded force to a plunger can be used to evaluate the usefulness of AIF in learning as compared with a terminal information feedback condition, because the bar pressing studies did not include a TIF control.

The plunger pressing task required the subject to press until a light on an oscilloscope connected to the plunger reached a target marked on the 'scope face. Terminal information was verbal or visual as the subject held pressure steady at the end of a trial and the screen hiding the oscilloscope was removed. TIF was found to be superior to AIF in test without augmented feedback. That is, a response feedback cue which was present during training and then removed led to poorer results than removing KR in a situation where the response feedback had never occurred. In fact AIF withdrawal gave an immediate and drastic loss of accuracy. Unfortunately no comparison was made between test scores after AIF training and those after no training so the claim of Fox and Levy (1969) that "Annett ... found positive transfer when the visual cues were withdrawn" (p. 170) cannot be substantiated.

Using a bar pressing task in which pressure which moved the bar 1mm moved a light spot 20mm on a screen AIF training Annett (1959) again found large errors in test. However when the bar was given a ballistic tap visual feedback was as useful as verbal feedback of "too little", "too much" or "just right". This may mean that no visual feedback could be used during the performance of the task but that it yielded terminal IF, or that subjects made inaccurate movements which they had to learn to correct rather than making the correct movement all the time and never experiencing error.

Annett suggested that AIF, by enabling subjects to perform accurately, may remove the experience of error which could be necessary for correct performance and so in one experiment he instructed subjects to aim at half the target pressure or at a pressure of half as much again as the target but he found that test performance did not differ from that after normal AIF. However the normal error experience in acquiring such a skill is of making attempts to reach the target and failing, and then approximating more and more closely to the correct pressure. In this way a modal value for the task is built up so that after having performed correctly for the several trials the subject who began incorrectly continues to produce the movement which has not been 'error tagged' over learning. Annett's instructed error is not a useful way of investigating whether or not difficulties in retention with AIF are due to lack of error information.

The statement by Annett that "to repeat a precise response is not a sufficient condition for learning that response even if the response is known immediately to be correct" (Annett 1959 p. 12), is disputed by Fox and Levy (1969) on the basis of their second reported experiment on arc drawing. Their task involved learning to draw a 16 inch arc subtended by a 225^{o} angle and they tested performance after 8 trials with AIF or 8 trials TIF, 8 trials on which AIF trials alternated with TIF trials and 8 trials on which the first four had no IF while the last four had AIF. Thus there were two groups with 50% AIF, one with 100% AIF and one with 100% TIF. Overall the groups which had 8 trials AIF and 8 trials TIF differed significantly in test, although Fox and Levy appear unwilling to recognise this. However the alternate trials of AIF condition showed very interesting results in that the trials without feedback showed error close to that found in the TIF condition. In addition, after 8 test trials there were no differences between the groups.

It is difficult to explain why those subjects who had eight trials with AIF should be less accurate on test than those who had eight trials with TIF while those with only half as many trials with any kind of information feedback are not. Fox and Levy suggest that studies of relative frequency of TIF trials which show that absolute frequency is in fact the critical factor when the number of trials with feedback is held constant (Bilodeau and Bilodeau 1958), is not valid for AIF as 4 IF trials seem better than eight.

The statement of Annett quoted above appears to contradict one made in the same year by Holding (1959). After finding that guided practice of one minute is as good for tracking as normal visual practice for one minute he states, " what seems to be necessary for the acquisition of a motor skill is knowledge of the correct response; and KR is merely an incidental, though common, means of achieving the correct response". It is interesting that Holding's result is at variance with other results from guidance studies and is based on a very short period of training just as Fox and Levy's is, although it is paralleled by the statement of Adams and Goetz (1973) that "the correct movement lays down a standard against which subsequent movements are compared for a determination of error" (p. 224). This last position was also based on evidence from a few learning trials.

Annett's results show extreme error after 50 AIF trials while Fox and Levy's show normal error (i.e. as with TIF) after four trials. If AIF is effective for learning it may only be so in the early stages of familiarisation with the task. The uncertainty removed after one AIF trial on a 16 inch arc drawing task is considerable as the required response could be of any size.

Considerable learning might be shown after a few AIF trials just as in TIF but after the initial stage is passed AIF may prove to be less useful.

Action information feedback does not allow a subject to differentiate the correct response from a range of responses, which may result in a weak memory trace, yet movements to a stop, which also do not allow experience of error, do result in accurate learning of the required distance (Holding and Macrae 1964). It may not be the accuracy of the movement which is important because accurate movements in some cases lead to learning but in others do not. Both Holding (1959) and Annett (1959) may therefore be correct, saved from contradiction by "sufficient" and "necessary". While the knowledge of the correct response may be necessary for learning it is not sufficient, at least where visual and kinaesthetic information are being processed simultaneously to control a movement as it is learned, but in which reliance is placed on kinaesthetic cues only for control during test.

Simultaneous input on two modalities might be expected to lead to a decrement in processing one type of input if the processing capacity of the channel were strained. However, Annett's (1959) results indicate a constant overestimation of the required pressure when AIF is removed, and he considers that if vision were so powerful that visual information were processed in preference to kinaesthetic information then errors on either side of the target would be expected when visual information was removed. Annett puts forward an intersensory explanation which suggests that visual and kinaesthetic data are combined into a single impression of movement so that modification of either visual or kinaesthetic data could affect the impression. This conclusion however, is based on the assumption that if "they have been attending solely to it (the visual cue) one would not predict the direction and extent of the subsequent errors" (Annett 1959, p.13, my emphasis). A visual dominance hypothesis does not necessarily mean that subjects attend soley to the visual cue, nor does the hypothesis that visual information distorts simultaneous kinaesthetic information mean that an intersensory effect is operating in which each modality has the same weight. If the two sources of feedback are not equally informative then the combination of the information into one sensory impression would lead to a bias in test performance such as Annett reports. Unless it can be shown that removal of kinaesthetic feedback also leads to errors in a predictable direction the evidence for an intersensory hypothesis is incomplete, and as was noted earlier, such evidence is difficult to provide.

In the experiment which Annett (1970) reports in support of the intersensory hypothesis the task was lever pulling with visual AIF for 10 trials followed by 10 trials without AIF. Three distances and three gains of display were used, although the shortest movement with the lowest gain and the longest movement with the highest gain were omitted. Again subjects overshot in test but this was related to both gain and distance. Overestimation was least with long movements and small gain and greatest with small movements and large gain. This means that where visual feedback was more informative than kinaesthetic feedback because the visual display was large while the movement was small there is most overshooting. Subjects appear to perceive a small movement as being larger than it actually is, if visual information tells them so.

If error is larger and positive over shorter rather than longer distances for pull tasks (Weiss 1954) such as that used by Annett

(1970), then the amount of visual information becomes the most important variable affecting Annett's results. Posner and Konick (1966) also report that proportionately less error was obtained with longer movements. If visual input were dominant in a situation where there was large display gain then it would be expected that removal of that input would result in overestimation of the required movement. Annett's (1970) results with a display smaller than the actual movement are the only results which suggest that it is not simply the relative size of the visual display which causes overshooting. However, if tasks of this sort are likely to cause overshooting (Weiss 1954), then these results alone do not substantiate an intersensory hypothesis as opposed to a visual dominance one. A visual dominance position would account for the rest of Annett's findings.

One of the most interesting findings of Annett (1959) although "an observation rather than an experiment" (p.11), is that many subjects reported that the bar which they had been learning to press felt stiffer when the visual display is removed. This may be explained by the fact that as subjects were overestimating the required pressure, i.e. pushing harder, they did not realise this but attributed the different kinaesthetic feedback they were experiencing to the bar, rather than to their own altered performance. Subjects' evaluations of their own performance may be related to the perceived increase in stiffness of the bar.

A similar illusion is reported in Annett (1970). Subjects typically were correct on their first attempt without the feedback cue but reported that it felt like an error, their response length then increased and subjects felt that they had improved. Unfortunately no quantitative results were offered about this effect but it does tend to confirm the suggestion that kinaesthetic feedback is overestimated if it has arrived with visual information which is greater than the movement being learned. It would be interesting to know whether subjects who had a visual display which was smaller than the movement also reported this effect.

Annett's (1970) report that the first test result was close to the target was taken by Fox and Levy (1970) as corroboration of their results, although in their 1969 paper the first responses after 8 AIF trials show much larger errors than any other condition. The indication from mechanical guidance studies that guidance is of use in the first few trials, but of decreasing use in later trials, may hold true for visual guidance or AIF. The accurate test results of Fox and Levy (1969) and Annett (1970) (first trial) may represent the short term effects of AIF while the very inaccurate results of Annett (1959) may reflect the long term experience of the task, and an increased dependence on the visual cue for the maintenance of performance.

In all of Annett's (1959, 1970) experiments visual information is supplied via a display rather than direct from the movement being made, while Fox and Levy (1969) allow subjects to watch their hands and see an indicator of their accuracy on the apparatus as they move. In the terminal conditions the slot in which the pencil was moved and the scale beside it were covered until the movement was ended, but cues from the position of the hand and arm were not altered. This means that subjects who had AIF trials before TIF trials did not have all the visual information from the task removed for TIF trials, but only part of it. Considerable amounts of visual information may have remained available. This is obviously related to the question of the size of the movements used in these two sets of experiments - very small movements give little extra information from arm movements while large movements in which movement is seen directly and not via a display may contain extra cues.

Other differences between Annett (1959, 1970) and Fox and Levy (1969) are that Annett's work does not differentiate between place and distance learning while Fox and Levy use distance only, and that the latter investigation looked at deterioration of test performance over time which Annett did not. Fox and Levy claim that "place learning seems .... potentially disadvantageous for subsequent no IF reproduction based on movement produced cues". (1970, p. 226). This, however, would have to mean that distance cues in Annett's studies were ignored as they were present together with place cues. As it is more likely that distance and place cues together lead to better retention than either separately (Stelmach 1974), other differences between these two pieces of research, such as number of practice trials, gain, stage of test measurement, and size and type of response, should be considered before the issue of place versus distance learning can be resolved.

2.6 Visual AIF and movement control theories

In the feedback oriented closed loop theory of Adams (1971) the perceptual trace is set up as a type of composite image of the feedback from all modalities used in the task. In Laszlo and Bairstow's (1971) account this is part of the standard or general referent, a position similar to that of Pew (1974), which equates the perceptual trace with the image of sensory consequences of the correct movement which is used to estimate the correctness of the movement made which is an instance of the schema for the task although it may not be the correct one for the current situation. The schema is presumably built up during practice when motor commands and sensory feedback are compared with performance accuracy and goals to modify subsequent movement.

Performance accuracy is known by some form of knowledge of results and in most types of training KR can be removed for test trails without disrupting any of the other sources of information which are used to estimate the accuracy of a response. If response produced feedback or sensory consequences of movement include continuous visual feedback which also produces KR then removal of such feedback could be expected to disrupt performance. However, if the KR function is important for learning, over a long period of practice a motor command for accurate performance might mean that the removal of visual AIF was no more detrimental than the removal of TIF.

Annett's report that subjects felt the correct movement to be an error suggests that they had a correct motor command operating but that the sensory consequences of the movement were distorted by the removal of the visual feedback leading to a change in response. In Adams' (1971) terms the memory trace is accurate but the perceptual trace has been misrepresented by the removal of a very powerful modality. This is stronger evidence for the existence of two separate traces, one used to produce, and one to evaluate the response than other subjective/objective error comparisons. Unfortunately Annett's (1969) result is not quantitatively substantiated and this would be necessary in order to show that response initiation and evaluation can be controlled in different ways.

This result is perhaps more clearly accounted for by a less rigid schema model such as that of Pew (1974) and Schmidt (1975). If a subject selects a movement instance for similar initial conditions and the same response specifications as for previous accurate responses and predicts sensory consequences and response outcome similar to those already experienced then, when AIF is removed, the predicted sensory consequences will not be met with. If preprogramming has occurred the first post AIF movement may be accurate but subjectively feel inaccurate because the predicted consequences do not arise. The next schema instance selected may be biased in favour of producing the expected sensory consequences given the new environmental conditions, especially as no other method of judging the accuracy of the response exists.

Thus, it is possible to show that the sensory consequences of a movement may be more important than previous experiences of the required response, that feedback is more important than response selection. This may be found with AIF because the response selection mechanism is weak in that it has not had to pre-determine a response before initiating it but has used the visual cue to control terminal accuracy during practice.

It is not clear what can be expected from extended AIF practice. If after a very long period of AIF training a task is learned this may mean either that the response selection is stronger - a motor programme exists, or that the sensory control has been delegated from vision to kinaesthesis, i.e. the subject may build up a motor programme more slowly with AIF as movement is guided by the visual cue so that the end of the movement need not be known when it is initiated, or it may require a long period of practice before the 'feel' of the task is finally learned and visual control drops out.

Visual guidance does not result in passive movement as mechanical guidance does. The subject does not know at the beginning of the first trial where the movement will end but after that there is as much information available about the movement as is available for a restrained movement, which results in accurate retention (Holding and Macrae 1964). Both of these types of training ensure that little error is made during practice, but visual AIF appears to be inferior as a learning cue, similar to passive learning in mechanical guidance conditions.

Restrained movement, passive movement, and visually guided movement provide some indications of the roles of commands and sensory feedback in learnt movement control. Both restrained movement and visually guided movement is initiated by the subject and neither allows error in practice, yet the removal of the visual cue has much more effect on performance than has removal of the restraining stop. Mechanical and visual guidance give similar results in performance and test, yet under mechanical guidance movement is not initiated by the subject and there is no visual information to conflict with the kinaesthetic cues.

The question of attention to kinaesthetic feedback is important here. Under both mechanical and visual guidance conditions subjects may not attend to the kinaesthetic feedback which they will be required to utilise to evaluate later responses. In the case of restrained movement this may not arise. Holding and Macrae (1964) do not report the speed of movement of subjects in the restrained condition but it may be that movements to a stop are made at considerable speed, perhaps even in a ballistic fashion, so that the response is completely pre-programmed, while slower guided movements require feedback control. Vince (1948) found that when subjects were required to displace a pointer towards a target they were very accurate with eyes open at slow speeds and much less accurate at movement times of less than 200 msecs although these became more accurate and remained so when made with eyes closed. If this speed of movement is more important than the type of training, it may be because for such movements motor commands are learned complete, with little demand for response feedback.

If the movement made is to a stop little attention is required for the later stages of its execution, even if it is much longer than 200 msecs. Ells (1973) used a secondary reaction time task and found that reaction time did not increase when subjects were also making a movement to a stop although the increase was found at the initiation of the movement. Feedback required no attention in a totally predictable movement, it may be correction or alteration of a movement which requires the attention.

The evidence that AIF is or is not useful in training is at best inconclusive. It does seem intuitively that repeating a movement a large number of times under visual control should lead to a gradual phasing out of that visual control either by a motor programme unit or by increased dependence on kinaesthetic feedback, especially when subjects know they are to be tested without the visual Cue. However, if during training the visual information is attended to more than the kinaesthetic as is suggested by Klein and Posner (1974), control may never be delegated. The Klein and Posner study uses a short - term memory paradigm rather than a learning one so this generalisation of their result may not hold, the predominance of vision over other sensory systems may change with practice. Other variables which influence the acquisition of a skilled movement should be controlled more carefully in an attempt to resolve the differences between Annett (1959, 1970) and Fox and Levy (1969).

Subjective reports of accuracy of performance and response characteristics of the equipment used have considerable potential as a tool for disentangling the 'feel' of a response from its accuracy. Given Annett's (1970) report of alteration of a correct response it would be expected that subjective and objective test scores will differ considerably for subjects trained under AIF conditions, indicating a weak perceptual trace (Schmidt and White 1972), unless, after a large number of trials, vision is phased out. On the other hand the kinaesthetic illusion of stiffness in the bar being pressed, in which a change in feedback is experienced because of the exertion of more force, indicates that response produced feedback is very important, although distorted, and may mean that subjects who have a large number of practice trials should become more susceptible to the illusion if they continue to depend on the visual cue and less susceptible if they are actually learning the task without that cue.

Action information feedback in the form of a visual cue is a potentially useful way of investigating the interaction of kinaesthetic and visual response-produced feedback and the degree to which such feedback is important in a relatively well learned task. It is necessary that the apparent contradiction between the results of Annett (1959, 1970) and Fox and Levy (1969) should be resolved.

The studies which follow have attempted to clarify some of the issues involved, by using three tasks with different characteristics. These are: bar pressing, similar to that used by Annett 1959, learning a time of movement, similar to the task of

Roy and Martenuik (1974), and a fairly large movement displacement task with some features of the task of Fox and Levy (1969). The variables investigated include amount of practice, speed of movement, gain, and attention to visual cues. The original intention was to attempt to understand the illusions reported by Annett which have considerable promise as a method of throwing light on the interaction between kinaesthesis and vision, but this made it apparent that variables such as those mentioned above were as important for the performance as the perception of the task.

Chapter 3

Introduction to experimental work

3.1 Overview of experiments

In the experimental work which follows several aspects of AIF training were considered in an attempt to clarify the roles of visual and kinaesthetic feedback in the learning of simple movements. The work began with a bar-pressing task similar to that used by Annett (1959), and an initial point of interest was the illusion, reported by him, that the bar becomes stiffer when the continuous visual cue used in training is removed. This study indicated that the illusion does occur, although not to the extent reported by Annett, but that it cannot be related to the extent of subjects' error in test, and it is not affected by increased amounts of practice. As actual test error was also little affected by increased amounts of practice the next step was an attempt to determine whether concurrent visual feedback was useful for reducing subjects' uncertainty about the task in the first few practice trials, or whether the amounts of practice given previously had been inadequate for the formation of a motor programme for the task. A terminal feedback group was included so that the efficiency of AIF as a method of training for this task could be assessed.

Observations of the speed of responding in bar-pressing indicated a wide range of practice speeds under AIF conditions, with some suggestions that AIF subjects were slower in practice than TIF subjects, i.e. they attended more to the response-produced feedback. In an attempt to control this, subjects were required to respond at set intervals. This meant that some subjects made fast, frequent movements, while others were less restricted in the time allowed for each movement. It was expected that those AIF trained subjects who practised at a high rate would be less accurate in practice but more so in test than those who practised more slowly (Annett 1959, Vince 1948). This result was found, but subjects in fast conditions were responding very rhythmically and it was not necessarily the increased speed which led to the improvement in test performance - the rhythm of the movements, or the interaction between the rhythm and the target pressure could also have influenced the results. A study of a range of movement times was therefore carried out with both an AIF condition and a no feedback condition for each rate. Consistencies of performance in conditions without any feedback at all would mean that either the rhythm or the rhythm/pressure interaction was very important in this task.

In all of these bar-pressing experiments terminal feedback was verbal as the equipment could not provide suitable visual KR. The visual display used for the AIF conditions was much larger than the actual movement made so there was more visual than kinaesthetic feedback from the movement. As it may be the predominance of visual feedback which leads to the inaccuracy in test performance, and to the illusion of increased stiffness, a terminal visual display is a more adequate control than verbal KR, and it enables the cueing properties of the continuous display to be isolated. Such a display was provided using the oscilloscope of a Dec PDP8 Lab E computer to give either continuous or terminal visual information. In addition, the size of the display was varied so that some subjects had the same display gain as in previous experiments while others had a much smaller display for the same movement. Although this was not a comprehensive investigation of the gain variable suggested by Annett (1970), it was intended to provide some indications of the importance of the display gain in this task.

In general in the bar-pressing studies the accuracy of practice movement was related to the time taken for the movement. This meant that it was difficult to isolate the effects of having a lot of time available to attend to the visual cue from those of a lack of experience of error in training. Subjects may learn poorly because they need to know what a wrong movement is like, or they may place too much emphasis on response-produced feedback because of the time which is available for the execution of the response. In an attempt to keep one of these factors constant a task was devised for a second group of experiments in which subjects were required to make a movement in a given time. Continuous or terminal visual information about performance was provided.

The first of these studies used both fast and slow movements, although it was not expected that the very fast movements would allow subjects to utilise the visual feedback. However, the results from the fast conditions are somewhat equivocal as subjects were confused about the nature of the task, and many subjects took a long time to learn that the visual display represented time and that they should use it to help them perform accurately. Subsequent experiments used target times of 1000 milliseconds or over as this allowed subjects to understand the task quite quickly.

When subjects were questioned as to the strategies which they had used in learning to time a movement many of them reported that they counted, whether or not they had a continuous visual cue available. This means that the effects of different types of feedback were operating on a verbal, or verbal-motor task, rather than on a motor memory task. This counting strategy, which seemed to prevent subjects from depending on the visual cue, was removed by requiring subjects to perform a secondary shadowing task while learning the timed movement. Differences between the AIF and TIF conditions should therefore be due to the effect of depending on a visual cue in a demanding situation. However, this task remained resistant to the extreme effects of continuous visual feedback which were found in bar-pressing, and made it possible that these effects occur only in the situation where subjects are learning to exert pressure with large gain on a controlling visual display.

To make sure that the AIF effect was not completely task specific, and to approximate the experimental situation of Fox and Levy (1969), a third task was devised. In this the subject was required to learn to make a sideways movement of twelve centimetres, and continuous or terminal visual information was provided. The target distance on the visual display was also twelve centimetres so the relationship between visual and kinaesthetic feedback was normal. A restrained movement condition was included in which a stop was inserted in the track during practice but removed for test. In this condition subjects could not make any errors during practice and use of this condition in conjunction with continuous visual feedback meant that the effects of accuracy in practice could be separated from those of the attention demanding role of visual feedback.

In summary, three different tasks were used to investigate the effects of visual AIF on the learning and retention of skilled movements. These tasks required very different responses and involved different relationships of visual to kinaesthetic feedback. Movement time, accuracy in practice, subjects' strategies and extended practice were some of the important aspects of skill learning studied with respect to these tasks. The research is reported in three sections, one for each type of task, and some conclusions are presented at the end of each section.

3.2 The measurement of error

Three main ways of measuring accuracy in performance tasks have commonly been used. These are - absolute error (AE), which is the mean of the subject's unsigned error scores, constant or algebraic error (CE) which is the mean of the signed error scores, and variable error (VE) which is the standard deviation of a subject's errors about the target (Henry 1974). Recently it has been suggested that absolute error should not be used as it is an unspecified function of constant and variable error (Schutz and Roy 1973). However, absolute error has been commonly used in performance studies and is intuitively meaningful as a measure of how accurate a subject has been rather than how consistent, or in which direction error has been made (Schmidt 1975).

Variable error indicates the precision with which a subject responds on successive trials but does not measure the accuracy of the response over these trials, while in some cases constant error may give scores around zero for many performance tasks - a repeated under and over shooting of the target. Where constant error is close to zero either variable or absolute error would represent the subject's performance in a more meaningful way. Some workers (e.g. Keele and Ells 1972) use VE rather than AE in the belief that the variation of a subject's scores round a target reflects the amount of learning which has taken place, thus using VE and CE as dependent variables in any one study should give a more complete picture of the error in performance than AE alone (Stelmach 1974).

Seashore and Bavelas (1945) have shown that as a movement is repeated it becomes more consistent even although the subject is never informed of the accuracy of the performance so that no learning can take place. If repeated execution of a movement without knowledge of results can influence an error measure then it may not be suitable for detecting performance differences after different types of training.

In the experiments reported here all three types of error measurement will be used where relevant. In those cases where direction of error is important CE will be used but where over and under shoots cancel each other out producing constant error scores around zero both AE and VE may be used to measure test performance, with VE being emphasized when consistency of performance is of interest.

3.3 Statistical analyses

Throughout this thesis the following convention is used for indicating the level of significance in statistical analyses:-

NS	not significant
*	$p \leq 0.05$
**	$p \leq 0.01$
***	$p \leq 0.001$

Chapter 4

Pressure Learning Experiments

4.1 Introduction

These experiments are based on the work of Annett (1959) and the apparatus used was very similar to his. Although his inter-sensory illusion was originally the main interest, other variables such as speed of movement and gain of display became important.

Although Russell and Martenuik (1974) consider torque to give kinaesthetic information they agree that much more information is available from amplitude. Annett's results with bar pressing may reflect the paucity of the information provided kinaesthetically as a result of exerting pressure. This may mean that AIF in the form of a continuous visual cue would not be disruptive in learning a movement of large amplitude because the increased kin-aesthetic information is sufficient to take over from the cues provided by vision during training.

If subjects in a terminal feedback condition can learn a pressure then either the kinaesthetic cues are adequate or there is a central motor command built up over practice. A central programming theory would predict that with continuous visual feedback sufficient practice of the bar pressing task (this could be a very large amount of practice) would lead to decreased monitoring of all response produced feedback and accurate test performance would be provided by the controlling programme so that after this practice the removal of a visual cue should not have a disruptive effect. This result would also be expected if control were totally delegated by the visual system after sufficient practice. The long practice required could be due to the strong attention demands of the visual cue, rather than to its overpowering effect on the kinaesthetic information.

When a continuous visual cue is removed subjects report that the bar has become stiffer. If this illusion persists after a considerable amount of practice and its size is not related to the actual errors made then it can be suggested that test performance is mediated by a motor programme while subjective feelings of stiffness require a monitoring of the kinaesthetic feedback rather than a central error detection loop, and it is here that the inter-sensory effect operates.

If a movement of large amplitude, with no display gain, could be found to show good retention after both AIF and TIF practice while a pressure or torque exertion task shows poor retention with AIF then feedback must be given a more important place in the learning of the latter task, and it becomes more likely that response produced feedback is controlling on-going movement rather than judging it after the movement has been completed.

These studies will not resolve these problems, but it is hoped that they throw some light on the problem of cross modal interaction in the feedback control of movement.

4.2 Pressure learning apparatus

A metal bar 25 mms wide and 6mms thick was clamped to a table top 29cms from the end to be pressed. General purpose strain gauges were mounted next to the clamp and connected in a bridge to a Devices polygraph. The clamped end of the bar was covered by a casing from which 11.5cms of bar protruded. Output from the strain gauge bridge was fed to a pen recorder unit and to an oscilloscope display. When the bar was pressed the pen recorder was deflected and a dot on the oscilloscope screen moved upwards. A control box enabled the spot on the screen to be stopped even though the pen was still recording.

The oscilloscope screen was masked apart from a slit 11 mms wide and 7 cms long which was marked by two horizontal lines, one 3 mms from the bottom of the slit and the other 4.5 cms above that. The lower mark showed the resting position of the bar and the higher one was the target.

Subjects were required to press on the end of the bar and a line was marked on it 15 mms from the free end to indicate the position within which the fingers should remain. When the correct pressure was exerted on this area the end of the bar moved down 3 mms. Thus a visual movement of 45 mms represented an actual movement of 3 mms, a display gain of 1:15. The movement of the bar in terms of the pressure exerted was very small, 3024 gms weight on the 15 mm section at the end of the bar moved it the required 3 mm.

The subject was seated on a swivel chair facing the oscilloscope, the screen of which was 115 cms from the floor and tilted slightly backwards. The table with the bar attached were to the side of the subject and could be moved to the left or right depending on the subject's preferred hand. The table top was 74 cms from the floor and as subjects were required to press the bar with arm extended and wrist comparatively straight the chair could be moved up or down depending on the length of the subject's arm.

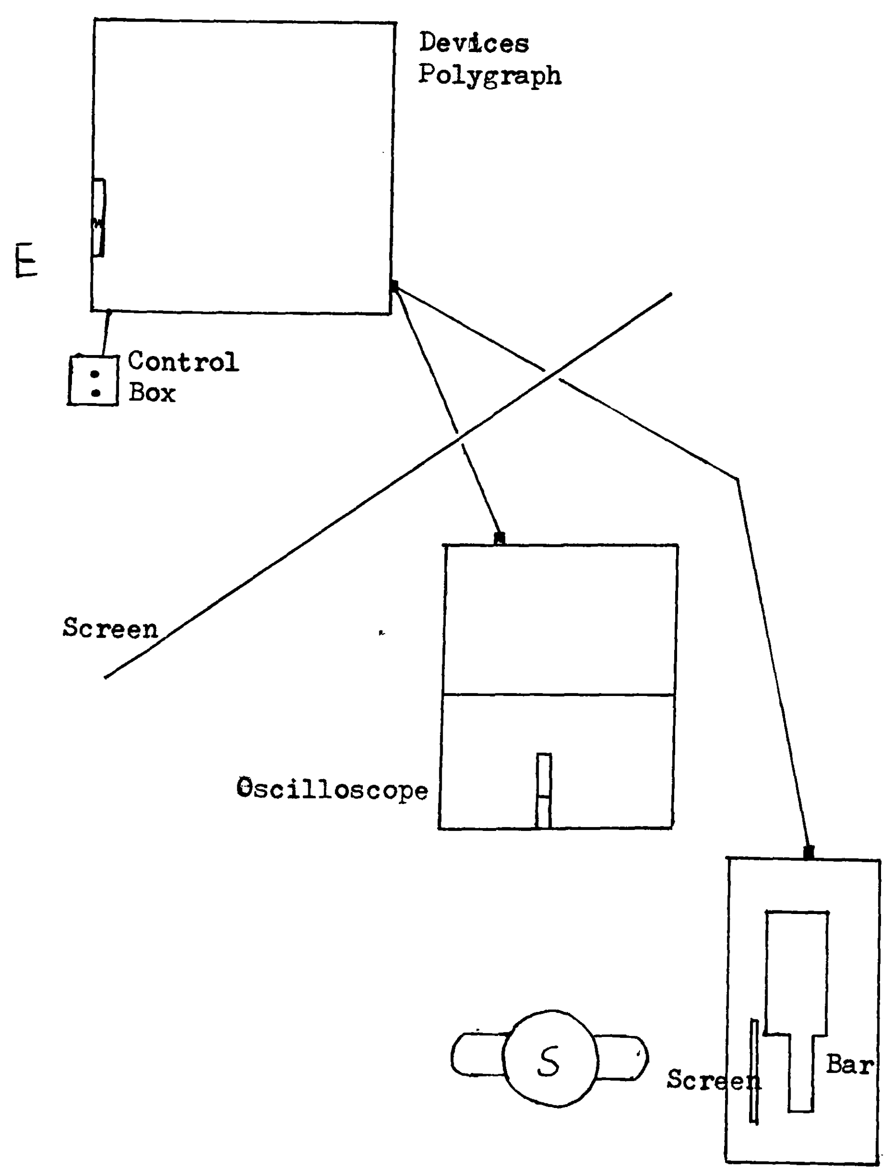
Both experimenter and the Devices polygraph were screened from the subject while the experiment was in progress and the bar itself was behind a small screen so that visual cues from the actual movement could not be used. This layout is shown in Figure 1.

Data was recorded in the form of pen deflections. The target pressure was represented by 20 1 mm squares on the recording paper and deflections were measured in millimetres to the nearest o.5 mm. The error score per trial was the number of mm squares difference between the subject's deflection peak and the target line on the record. When the light spot was held on the target line on the oscilloscope the error score was therefore zero.

Fig. 1.

Bar Pressing Apparatus. Layout:

Experiments 1-4



4.3 Experiment 1: Objective and subjective test error after extended practice with AIF.

Introduction

Method

Subjects

Apparatus

Procedure

Results

A) Test Error

B) Subjective Ratings
   i) Increased stiffness
   ii) Initial stiffness

C) Practice Speed

Discussion

Introduction

Annett (1959) has reported that subjects who learned to press a bar while watching a free moving visual cue tended to feel that the bar was stiffer when the cue was removed. It is not clear from his account whether subjects expected the light cue to be removed or not and he reports that a feeling of a jolt in the fingers was experienced by some subjects when the equipment broke unexpectedly. This 'jolt' might simply mean that the subjects had faith in the equipment being used and assumed that if they pushed harder the light spot would move. In other words, the jolt, and possibly the illusion of increased stiffness, may be due to subjects actually pressing harder on the bar and interpreting the feedback as the bar pressing back at them.

The effect of the visual feedback may be to convince subjects that the bar moves easily as the visual display is much larger than the actual movement and may enable discrimination to be made which could not be made without it. When this cue is removed pressure cues may have more attention paid to them and the different perception of kinaesthetic feedback from what was intended to be the same movement may give rise to the feeling that the bar itself has changed.

If subjects who make large errors report that the bar is stiffer while those who are accurate do not, it seems that the illusion is simply a result of the extra force being applied, while if accurate subjects are also susceptible to the illusion, visual input may be said to have dominated the kinaesthetic input to the extent that without the former the latter is not recognised.

The number of training trials used is also a factor, both in the retention of the task and the perceived increase in stiffness. It would be expected that increased retention would result from a large number of training trials. If the AIF operates as a learning variable then more practice with it should mean better performance in test, but if the visual cue is only a performance variable then subjects may become more and more dependent on it so that retention may be worse after a large number of practice trials.

The interaction of the visual feedback and amount of practice is expected to affect the perceived stiffness of the bar during test. If the task is not being learned during practice but merely performed, then the visual feedback is of great importance and increased exposure to the task may not only increase the dependence upon this feedback but also lead to a greater illusion of stiffness in the bar. If the task is learned after a long period of practice it seems likely that as the central trace develops the visual feedback will become less rather than more necessary and so the illusion should not be so great. It is possible however, that even after an accurate test trial, initiated centrally, the kinaesthetic feedback available will be evaluated rather than totally ignored. This is related to the earlier point about the interaction between the size of error made and the illusion perceived. If a task is retained better after a large number of trials but the illusion persists in spite of the accuracy then feedback is being evaluated after the response is made.

The independent variables in this experiment are amount of practice and warning of test. If Annett's (1959)jolt to the fingers is simply an artefact of the unexpectedness of the stopping of the light spot, then those subjects who were not warned that the cue will be removed should make greater errors and perceive more stiffness than those who were warned that this would happen. Three levels of practice are used and subjects were either warned or not warned that the light would be stopped.

The only definite prediction made was that subjects who were not warned would press harder in test and possibly perceive the illusion more strongly than those who were warned. The interaction of the practice and perceived stiffness with warned subjects cannot be predicted given that so little is known about the task and no data on the illusion has been reported at all. However it was expected that some differences in performance would be found after differing amounts of AIF practice.

Method

Subjects

Subjects were 54 undergraduate and postgraduate students at the University of Leicester. 26 were male and 28 female. Ages ranged from 18-27 years with a median of 21 years. All but 2 subjects said that they preferred to use their right hand. All subjects were naive to the task.

Apparatus

The standard bar pressing apparatus was used.

Procedure

Subjects were randomly assigned to one of six groups balanced for sex as far as possible. Each subject was tested once only.

All subjects were seated in front of the oscilloscope, with the table with the bar attached on the preferred side. They were asked to adjust the chair until they could sit comfortably with the fingertips of their preferred hand on the end of the bar and the arm straight. When they were settled in this position they were asked to remove the hand from the table and to say whether the dot on the oscilloscope was touching the bottom line (which was pointed out to them). The equipment was then adjusted until the subject reported that the dot and the line were touching.

All subjects were then told, "In this experiment you will try to learn to press with a certain pressure on this bar. The light is there to guide you. When you have exerted the right amount of pressure the light will touch the top line. What you have to do is to press the bar and try to remember the amount of pressure required to make the dot touch the top line. Release the bar after each press so that the same amount of pressure can be exerted each time. Repeat the pressure when you are ready. Remember, the light is only a guide, you are trying to learn the amount of pressure required".

Subjects in groups 4, 5 & 6 (warned condition) were told, "When you have practised I will stop the dot and you will have to try to exert the correct pressure without it. I will warn you immediately before I stop the dot".

All subjects were asked if the task was clear and if not the instructions were repeated.

Practice consisted of 50 presses in groups 1 and 4, of 100 presses in groups 2 and 5, and of 200 presses in groups 3 and 6. Subjects in groups 2, 3, 5 and 6 had one minute of rest after each 50 presses. Immediately following the practice trials each subject had 10 test trials in which the light was stopped and s/he was required to reproduce the pressure.

Subjects in groups 1, 2 and 3 were reassured after the dot was stopped and told that the equipment was not broken but that they were to keep trying to reproduce the pressure which they had been practicing. Those in groups 4, 5 and 6 were told, "I am stopping the dot now" immediately before the light was stopped, and further reassured if necessary.

Before commencing practice all subjects were allowed to practice twice with the block in place under the bar, so that they could see that the dot did in fact go to the top line when they exerted the right pressure. This also enabled the experimenter to check that the equipment was recording properly and for this reason was repeated at the end of the experiment.

After the test all subjects were asked to rate (a) the initial stiffness of the bar on a five point scale ranging from 1- not stiff to 5- very stiff, and (b) any change in stiffness when the dot stopped on a seven point scale ranging from (1)- much less stiff, to (7)- very much stiffer, with (4)- the same.

Results

A) Test Error

The mean absolute error scores for each subject calculated over 10 test trials are shown in Table 1. A two-way analysis of variance with the presence or absence of warning and amount of practice as the factors showed that there was a significant difference between the results of those subjects who were warned and those who were not (Table 2), but that increased amounts of practice did not affect test scores. There was no interaction between the two factors.

Some subjects made such large errors in test trials that the recording equipment was unable to deal with them. When the recording pen was deflected as far as possible a maximum (M) score,

Table 1 Mean absolute error scores in test with 3 amounts of practice and 2 conditions of preparedness.

		Number of practice trials: 50	100	200
Unwarned	Mean	7.63	8.81	8.61
	S.D.	4.56	5.21	3.38
	Range	1.55 - 16.75	2.95 - 21.20	4.0 - 14.25
Warned	Mean	5.52	5.17	4.62
	S.D.	3.99	4.43	2.27
	Range	1.50 - 14.95	0.85 - 16.20	0.75 - 9.75

Table 2 Analysis of means in Table 1

Source	DF	SS	MS	F	P
1 Warned/ unwarned	1	142.19	142.19	7.59	**
2 Practice	2	1.88	0.94	0.05	NS
1 x 2	2	9.06	4.53	0.24	NS
Within	48	898.91	18.73		
Total	53	1052.04			

equal to 24 error units (120% error), was obtained for the subject on that trial. There were two subjects who between them gave 3 instances of the maximum score in the warned condition, and nine subjects and 15 instances in the unwarned condition. These scores were given the value of 24 in the calculation of mean error scores and as the true score is probably larger than this some subjects have smaller mean absolute error and variable error scores than they should have. As the majority of these underestimated scores are in the unwarned condition the effect is to decrease the difference between the two main conditions, for both types of error score. As this difference is quite clear with underestimated scores no adjustment has been made.

If subjects were not warned that the visual cue was to be removed they made more errors than those who were warned beforehand. However, this was not because subjects pressed much harder immediately the cue was removed. Error on the first test trial was not always an overestimate for unwarned subjects while subjects who were warned made no error at all in a few cases and overestimated on others. (Table 3).

<u>Table 3</u> Mean constant error on the first trial after the feedback was removed.

		Number of practice trials		
		50	100	200
Unwarned	Mean	2.28	6.83	7.39
	S.D.	8.16	8.04	11.16
	Range	-5.0-24.0	-6.0-20.0	-7.5-20.0
Warned	Mean	4.94	3.67	3.44
	S.D.	3.68	3.26	3.52
	Range	1.0-7.0	0-11.0	0-12.0

Because of the large differences in within group variance in these first scores analyses of variance are inapplicable, but as can be seen from the range of error scores in each condition over 10 trials (Table 4) many subjects in the unwarned conditions went on to make very large errors. The low first trial error score for these subjects may mean that because of their surprise when the visual cue was removed they did not finish the movement which they intended. Those subjects who scored the maximum error on the first trial may have understood that the cue was supposed to have stopped so they could perform in a more expected way by overestimating the target. On the other hand they may have pressed harder in order to make the dot on the display move. Unwarned subjects provide results which are impossible to interpret in terms of error in the first test trial.

For warned subjects a Kruskal-Wallis analysis of variance on the first error scores for the three practice scores (AE) showed that there was no effect of increased practice ($H = 1.54$ $df = 2$ $p > 0.05$). The initial test score would appear not to differ after large amounts of practice from that after small amounts, just as the mean test error does not differ.

The change in performance over test trials for unwarned subjects is borne out by variable error scores (Table 5). Non-warned groups show much larger variation in within subject responding. A two-way ANOVA on these scores confirmed this difference between warned and unwarned groups (Table 6), and indicated that the practice conditions also differed. This last result is probably due to the low VE scores in the 100 practice, unwarned condition. These subjects made quite large errors throughout test.

Table 4 — Range of signed error scores for each subject

	Number of practice trials		
	50	100	200
Unwarned	-1.0 - M	6.0 - 11.0	-4.0 - 11.0
	-3.0 - 13.0	5.5 - 13.0	0 - 22.0
	-5.0 - 12.0	-6.0 - 10.0	-7.0 - M
	-1.0 - 12.0	-3.0 - 8.0	3.0 - M
	-1.0 - 14.5	-7.0 - 1.5	-9.0 - 6.0
	-1.5 - M	2.0 - 23	-7.5 - 10.5
	-4.0 - 1.5	4.0 - 8.5	-5.0 - M
	-7.0 - M	4.0 - 22.0	6.5 - M
	-0.5 - 14.0	17.5 - M	-10 - M
Warned	5.0 - M	3.0 - 8.5	0 - 2.0
	6.0 - 12.0	0 - 7.5	2.0 - 8.5
	0.5 - 3.0	0 - 8.0	0 - 7.0
	1.0 - 7.0	-2.0 - 1.0	-0.5 - 9.0
	0.5 - 3.5	1.5 - 7.5	1.0 - 12.0
	1.5 - 12.0	-1.0 - 2.5	1.0 - 5.5
	4.0 - 6.5	3.0 - 13.0	1.5 - 10.0
	-10.0 - 6.5	2.0 - 11.0	3.0 - 13.5
	-3.0 - 3.0	10.0 - M	1.0 - 10.0

M = maximum error score

(24 for purposes of mean error calculation).

Table 5 Variable error scores for 10 test trials. Warned and unwarned subjects over three amounts of practice.

		Number of practice trials 50	100	200
Unwarned	Mean	6.42	3.44	6.56
	S.D.	3.35	1.76	1.71
	Range	1.78-14.51	1.45-6.38	3.61-8.65
Warned	Mean	2.61	2.37	2.38
	S.D.	1.79	0.99	0.92
	Range	0.77-6.83	0.99-4.17	0.72-3.72

Table 6 Analysis of Means in Table 5

Source	DF	SS	MS	F	Prob.
1 Warned/ not warned	1	118.87	118.87	28.37	**
2 Practice	2	28.76	14.38	3.43	*
1 x 2	2	24.85	12.42	2.96	NS
Within	48	201.21	4.19		
Total	53	373.69			

B) Subjective Ratings

i) Increased stiffness

None of the subjects used the two lowest ratings-very much less stiff, and much less stiff. Frequency of occurrence of the other rating categories are shown in Table 7 and it can be seen that there is little apparent difference between the warned and unwarned conditions except that the unwarned condition uses the most extreme change category most often and the least stiff category least often. However, a chi^2 test on the occurrence of these ratings with warning/no warning and rating as dimensions gave $X^2 = 3.73$ which is not significant (df = 6, $p > 0.05$).

When all increased stiffness ratings are combined it is seen that the 'stiffer' categories are used more often than the 'less stiff' or 'same' categories. A chi^2 test of the overall frequency of occurrence of ratings under these three headings was performed with expected frequencies equal to the total number of subjects times the number of rating categories under the heading, divided by the total number of categories (seven). The result ($X^2 = 21.56$ df = 2 $p < 0.001$) indicated that subjects did not use the categories with equal frequency. A further chi^2 of these ratings using two headings only - 'stiffer' and 'not stiffer' - with expected frequencies calculated in the same way, gave $X^2 = 5.93$ (df = 1 $p < 0.02$). Thus, both warned and unwarned subjects considered that the bar had become stiffer when the visual cue was removed.

Annett (1959) has reported that the effects of feeling such a bar become stiffer when the light stopped was "present in both experienced and naive subjects and appears to be relatively independent of factors such as the amount of practice and set" (p. 11). This would appear to be confirmed by the present results

Table 7

Frequency of occurrence of ratings of increased stiffness on a 7 point scale from 1: very much less stiff to 7: very much stiffer with 4: the same*

No of practice trials:	Unwarned					Warned					Total				
	3	4	5	6	7	3	4	5	6	7	3	4	5	6	7
50	1	3	3	1	1	2	2	4	1	0	3	5	7	2	1
100	1	3	1	1	3	1	4	1	1	2	2	7	2	2	5
200	0	1	2	2	4	2	2	1	3	1	2	3	3	5	5
Total	2	7	6	4	8	5	8	6	5	3	7	15	12	9	11

* Ratings 1 & 2 did not occur and are omitted from the table.

that is, subjects who expected the dot to stop perceived the bar as stiffer afterwards as often as did those who were not expecting a change and this was not affected by amount of practice. However, groups used here are very small for the application of chi^2 tests and the tendency for the subjects with most practice (200 trials) to rate the change in stiffness more highly than other groups is seen more clearly in mean ratings for each condition (Table 8) - the 200 trials unwarned condition has the highest mean rating.

Table 8

Increased stiffness estimation: Mean ratings for each of 6 conditions.

	No of practice trials		
	50	100	200
Unwarned	4.78	5.22	6.0
Warned	4.44	4.89	4.89

The difference between groups 3 and 6 (200 trials, warned and unwarned) was tested using a Mann Whitney 'U' test which was significant ($U = 22$ (9,9) $p < 0.01$). The removal of the visual cue without warning may make more difference to subjects who have had most practice and perhaps become most dependent on the cue. However as no differences were found between the three practice conditions when subjects were unwarned ($H = 3.66$ $df = 2$ $p > 0.05$), this can be at best only a suggestion.

ii) Initial stiffness

These ratings were intended mainly as a check that the task was perceived in a similar way by most subjects and the overall occurrence of ratings (Table 9) indicates that most subjects used the ratings 3 and 4 - medium stiff and rather stiff, with no differences between conditions. This was confirmed by a chi^2 test on overall total frequencies with expected frequencies being the total number of subjects divided by the number of categories. ($X^2 = 34.7$ (5, 6) $p < 0.01$). As 42 out of 54 subjects chose these categories it would seem that the task was perceived in a similar way by most subjects.

Table 9

Frequency of occurrence of ratings of initial stiffness on a 5 point scale from 1: not stiff to 5: very stiff.

No of practice trials:	Unwarned					Warned					Total				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
50	1	3	4	1	0	0	2	4	3	0	1	5	8	4	0
100	0	1	3	5	0	1	1	1	5	1	1	2	4	10	1
200	1	0	6	2	0	0	1	4	4	0	1	1	10	6	0
Total	2	4	13	8	0	1	4	9	12	1	3	8	22	20	1

If a relationship were found between these initial stiffness ratings and test error scores this would imply that there was an effect of task difficulty on performance. However correlations between these two measures were very low for all groups (see Table 10).

Table 10

Correlation between initial stiffness rating and mean AE test score for 6 conditions: Spearman's rho.

	No of practice trials		
	50	100	200
Unwarned	0.12	-0 .23	0.29
Warned	-0.19	-0 .49	-0.04

The initial stiffness rating may be important in evaluating subjects' change of stiffness rating - e.g. some subjects may tend to make low ratings on both. Rank order correlation coefficients indicated that this was not the case for the unwarned groups ($r = 0.08$ $n = 27$) but for the warned subjects (who could not be said to press harder because they were startled or thought the equipment was broken) there was a relationship ($r = -0.61$ $n = 27$ $p < 0.01$). This indicates that those who felt the bar to be not very stiff initially tended to feel it was stiffer without the visual feedback than did those who felt it was quite stiff initially.

The initial rating does not show a wide spread of judgments, most subjects chose the central categories, and this rating is not related to the error score in test although for the warned subjects it is related to the change of stiffness rating. Thus, although the task was reasonably similarly perceived by the subjects regarding the stiffness of the bar, initial perceptions were negatively correlated with perception of change for warned subjects.

C) Practice speed

A measure of practice speed was obtained simply as the paper in the recorder moved at 5 cms per minute. Thus the distance taken to record indicated the time required for the task. Mean practice speeds ranged from 8.93 presses per minute to 62.99 presses per minute.

The speed of practice was correlated with the absolute mean error in test performance for warned and unwarned subjects, in the three practice conditions. In no condition was the correlation significant (Table 11) although in the 200 practice trials warned condition it was quite large ($r = 0.50$).

As the range of speeds was so great the errors found with extremes of speed were also considered. The error scores of subjects who had practised at a rate of over 40 presses per minute and those who practised at under 20 presses a minute were compared for the warned and unwarned test conditions (i.e. groups 1, 2 & 3 and groups 4, 5 & 6). Very few differences were found (Table 12), but this may be partly due to the small numbers of subjects who practised at a very fast rate. For the warned condition, in which the effects of rate of practice, if any, are not confounded with the effects of removing the visual feedback, a Mann-Whitney 'U' test on the error scores of fast and slow performers was not significant ($U = 22$ 4, 10 $p > 0.05$).

Speed or rate of practice does not have a clear effect on test performance in this case.

Table 11

Correlation coefficients for speed of practice and mean AE in test for 6 conditions: Spearman's rho.

	No of practice trials 50	100	200
Unwarned	-0.38	0.02	0.35
Warned	-0.42	-0.37	0.50

Table 12

Mean AE scores for subjects who practised very fast and those who practised very slowly

	Fast (over 40/min)	Slow (under 20/min)
Unwarned	8.51 n = 4	7.67 n = 6
Warned	5.64 n = 4	6.06 n = 10

Discussion

These results indicate that for a bar pressing task with continuous visual feedback in which the movement/ display gain is 1:15 two hundred practice trials do not lead to more accurate test performance than do fifty. Warning subjects in advance that they will be tested enables them to perform more accurately when the visual cue is removed than those who are not warned.

Subjects tended to rate the initial stiffness of the bar in a consistent way and they reported that when the light cue was removed the bar became stiffer. For those subjects who were warned, there was no relationship between error score immediately after the continuous feedback was removed and the increase of stiffness rating, while there was a small relationship for those who were not warned.

It had been hoped that the illusion of increased stiffness in the bar would be related either to amount of practice or to actual error in test, that is, that the illusion results from the amount of dependence on the visual cue or from subjects pressing too hard and interpreting their proprioceptive feedback as being due to a change in the bar. Those subjects who were not warned tended to make larger errors during the test trials, many of them pressing twice as hard as the target and these subjects also tended to rate the stiffness increase as being greater, so the second explanation cannot be completely ruled out, although it is difficult to see why the relationship should not hold for warned subjects, some of whom also made very large errors.

The failure to detect any increase in estimate of the illusion with practice may be due to the small numbers of subjects used. The attempt to alter subjects' dependence on the visual cue by increased exposure to it had no effects on either subjective or objective measures of performance.

Objective measures yielded only the information that experimental paradigms in which the subject is not warned that the feedback will disappear are likely to lead to very large errors or to produce responses which are difficult to interpret. Warning subjects that the cue will be removed makes it explicit that kinaesthetic cues are important in the task and, by directing subjects away from the visual cue, makes a result which indicates dependence on it even more striking.

It is, however, impossible to indicate the effect of AIF training unless it is known that the task can be learned more easily, or to a greater standard of accuracy, using terminal feedback. It is clear that within the limits of the practice given in this experiment an increased amount of practice does not improve learning. This may be because the subjects had learned as much as possible after 50 trials with AIF so that more trials showed little improvement, or because the task was so difficult that even with extended practice little improvement could be shown.

Some subjects did perform very accurately when the cue was removed although it is not clear that these subjects had attended to the light in the expected way. Some subjects admitted that they had tried to push the bar without watching the light and then looked at its position when the movement was completed, thus providing themselves with TIF. It is impossible to rule out such strategies but if very large errors persist with some subjects it may have to be concluded that AIF training is unhelpful when subjects actually use it.

4.4 Experiment 2: Guidance and delegation: very small and very large amounts of AIF practice.

Introduction

Method

Apparatus

Subjects

Procedure

Results

Absolute error

Constant error

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First test scores

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Discussion

Introduction

It was suggested in the reviews of visual and mechanical guidance studies that these types of training might be helpful for the first few trials in which the subject was being familiarised with the task, but that learning with terminal knowledge of results was more efficient over later trials. The finding in Expt. 1 that there was little difference between performance after 50 AIF trials and that after 200 such trials may mean that subjects have made all the use they can of the AIF in the first 50 trials. In addition, it became apparent during Expt. 1 that the task was difficult, and without a TIF control group it is impossible to say whether or not subjects actually can perform more accurately than they did in this experiment.

To clarify these points the AIF 50 trials group was retained and performance compared with that after 2, 5, or 400 AIF trials. If AIF is effective only at the early stages there should be little difference in retention shown by the groups, if however, AIF is only relatively ineffective as a learning cue and does allow some slow learning then performance after 400 trials may be better than that after 50 trials. A 50 trial TIF condition was also added to find out how well this task could be learned under terminal KR conditions. If Annett's (1959) plunger pressing result is correct, performance without additional feedback should be better after TIF than that after AIF practice.

Annett (1959, 1970) has suggested that subjects press too hard after AIF training, i.e. their error is one of overestimation, and he argues that this indicates the influence of the large, informative visual display on the small amount of relatively uninformative kinaesthetic feedback available. To confirm this a random control group was included. Subjects in this condition received no training at all and were given no feedback of any kind when they pressed the bar. Their results should err on both sides of the target pressure. This group also acts as a control for learning having taken place in the other conditions. Trained subjects who perform as badly as untrained ones cannot be said to have learned anything at all.

A final point is that of retention over time. A subject's first response, or first few responses, after AIF is removed may be fairly accurate when compared with those of TIF subjects, but if unrehearsable cues are being used such as those from distance learning then traces established under AIF training may decay quickly. In this experiment subjects were tested immediately after practice and retested after an interval of 10 minutes in an attempt to provide evidence for such differential decay, if it occurred.

Method

Apparatus

The standard bar pressing equipment was used.

Subjects

Subjects were 48 undergraduate and post-graduate members of Leicester University. There were 24 males and 24 females. Ages ranged from 19 years to 28 years with a median of 21.

Procedure

Subjects were randomly assigned to one of 6 groups which were balanced for sex.

Group 1 This was a random control group. Subjects, when seated with the bar on their preferred side were told,

"In this experiment other people learn to exert a certain pressure on this bar. I want you to press the bar at the pressure which you think they might use. You will not be told the correct pressure, just guess. Press the bar, release it, press it again and so on until I tell you to stop. Always try to keep your finger tips within this area at the end of the bar."

After 10 such presses Ss were asked to wait for 10 minutes and then requested to press again in the same way.

Group 2 Subjects had 2 practice trials with visual action information feedback. Instructions to subjects were as for warned conditions in Experiment 1 except that subjects were told "You will have two practice trials in which to learn the pressure before I stop the dot." When the dot was stopped Ss had 10 test trials, then a 10 minute rest interval followed by 10 retest trials.

Group 3 As group 2 except that subjects had 5 practice trials with AIF.

Group 4 As group 2 except that there were 50 AIF practice trials (as group 4 in Expt. 1) and subjects were not told how many trials they would have.

Group 5 As group 2 with 400 AIF practice trials with 1 minute of rest after each 50 trials. Subjects were not told beforehand exactly how many practice trials were required of them.

Group 6 Subjects in this condition never saw the moving light spot. Instead they received verbal terminal feedback from

E after each group of 5 trials. This feedback was vague and varied from "just about right" to "150% too hard". Percentages of error were approximate - 10% 25% 50% and 100% being used most often, together with the direction of the error. Subjects were told:

"In this experiment you will try to learn to press with a a certain pressure on this bar. Press the bar, release it and then press again, trying to keep your finger tips within this area. When you have pressed a few times I will tell you how accurate you are being, try to change the pressure so you are as accurate as possible. When you have been learning for some time I will stop telling you how well you are doing and you must continue to press as accurately as possible."

After 50 practice trials there were 10 test trials, followed by a 10 minute rest and 10 retest trials.

Subjects in all groups were asked if the instructions were clear before they began and if necessary further explanations were made.

Results

Absolute error

Mean absolute error for each subject calculated over 10 test trials is presented in Table 13. As some subjects in the previous experiment had pressed to the limit of the recording equipment the extent to which the pen could be deflected was increased in this study so that the maximum error recorded was 30 error units. In spite of this increase two subjects again scored maximum error,

Table 13 Mean absolute error scores after six conditions of practice: test and retest

Absolute error scores: test

Group	1 No Practice	2 2 AIF	3 5AIF	4 50AIF	5 400AIF	6 50TIF
Mean	8.79	8.99	9.08	5.03	4.69	2.63
S.D.	2.73	5.20	6.85	3.70	2.51	1.42
Range	5.4-13.00	1.95-18.00	3.80-24.70	1.75-13.50	1.35-9.20	1.25-5.25

Absolute error scores: retest

Group	1 No Practice	2 2 AIF	3 5AIF	4 50AIF	5 400AIF	6 50TIF
Mean	9.80	11.25	16.75	7.51	5.18	3.19
S.D.	4.40	5.22	6.67	6.42	2.61	1.22
Range	3.25-16.60	4.20-18.25	8.50-29.20	1.25-12.90	1.90-8.55	1.40-4.70

one in the no practice condition with one instance, and one in the AIF 5 condition with three instances in test and nine in retest. Means and standard deviations in this condition are therefore smaller than they should be, but as these are larger than in other conditions anyway true values could only confirm any differences.

Inspection of the means and standard deviations of test scores for the six groups indicates that the variances for the groups are not homogeneous. This is confirmed by Hartley's F max test which rejects the hypothesis that the variances are homogeneous in both test and retest ($p < 0.01$ in both cases). As the assumptions necessary for a parametric analysis of variance are not fulfilled Kruskal Wallis analyses were performed on test and retest scores. These both indicated that the groups differed on these measures. (Test: $H = 19.18$ $df = 2$ $p < 0.01$, retest: $H = 23.45$ $df = 2$ $p < 0.01$).

Results from the five experimental groups were compared with those from the no practice condition, using Mann-Whitney 'U' test. Groups 4, 5 and 6 (those with 50 or more practice trials of any sort) made smaller errors on test than group 1 (no practice), while groups 2 and 3 did not differ from group 1. On retest, only groups 5 and 6 (400AIF and 50TIF) were better than no practice controls, while group 3 (5AIF) was actually worse (see Table 14).

Further Mann-Whitney 'U' tests compared results of group 6 (50TIF) with those of the AIF trained groups. Subjects in all four AIF conditions were less accurate in test and retest than those in the TIF condition (Table 14).

Table 14 AE: Mann Whitney 'U' summary: Groups 1 and 6 compared with all others.

Test

	2 AIF2	3 AIF5	4 AIF50	5 AIF400	6 TIF50
1 No practice	31	24.5	12*	8.5**	0***
6 TIF50	5***	3***	15*	15*	-

Retest

	2 AIF2	3 AIF5	4 AIF50	5 AIF400	6 TIF50
1 N.P.	25	11*	18.5	11*	5***
6 TIF50	3***	0***	15.5*	15*	-

The finding that subjects who had 5AIF trials made more errors after a 10 minute interval than they had immediately after practice was confirmed by Wilcox on tests which indicated that there were no significant changes in the other groups ($p > .05$), but as every subject in group 3 was worse on retest than on test, T was equal to 0 ($p < 0.01$).

In general, over test and retest, absolute error scores indicate that 50 and 400 AIF trials and 50 TIF trials were better than no practice at all, while 2 and 5 AIF trials were not. 50 and 400 AIF trials were not as successful in producing stable accurate performance as were 50 TIF trials.

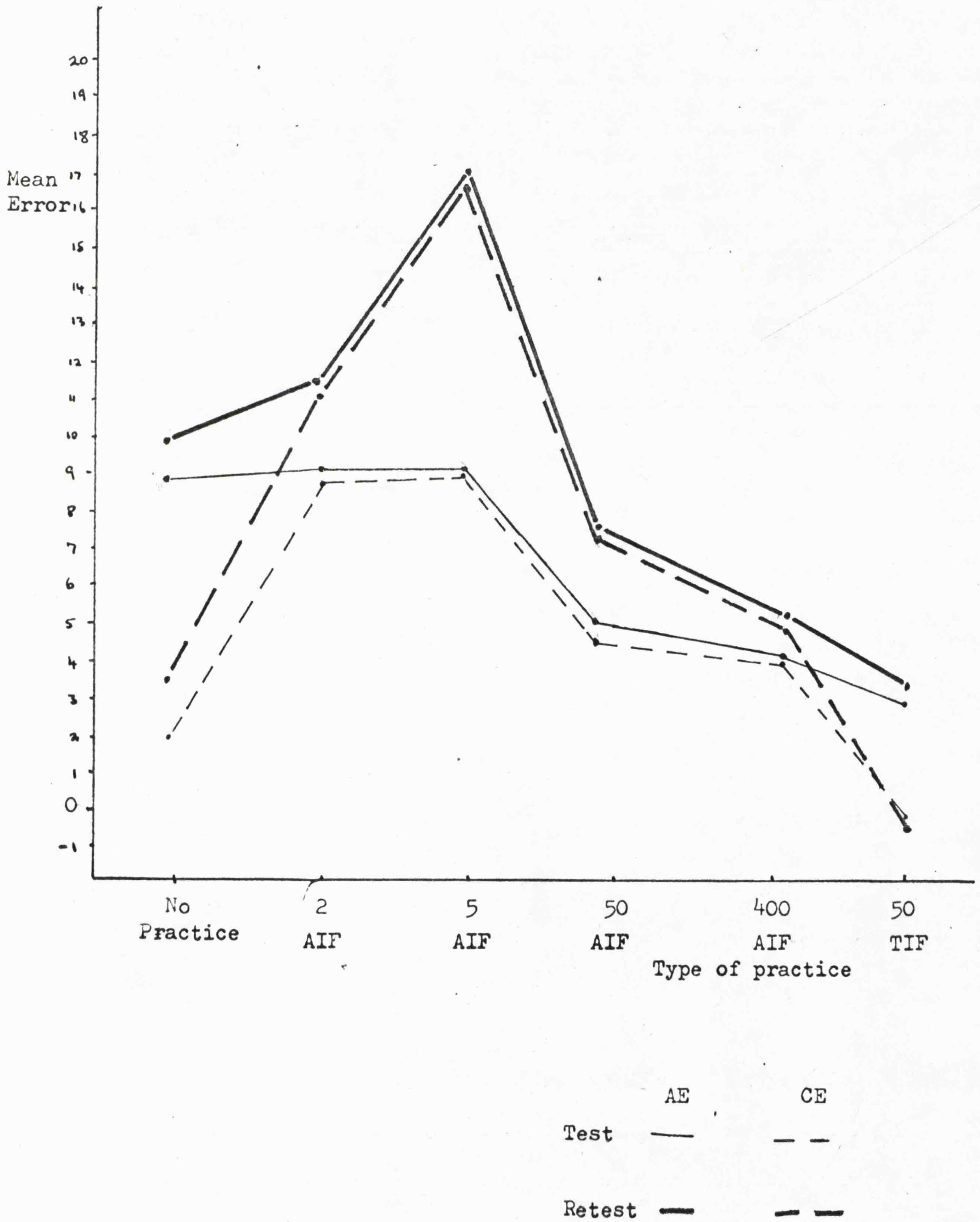
As it was found in the previous experiment that increasing amounts of AIF practice (over 50 trials) appear to effect little improvement in retention it is interesting that in this case subjects in the 400AIF condition still performed better in retest than no-practice controls, while the 50 AIF condition did not. This may indicate a reminiscence effect after a rest period following relatively massed practice.

The increased error in retest of the 2 and 5 AIF conditions suggests that small amounts of AIF training were exceedingly detrimental to subjects' ability to remember a pressure over an extended period. As the retest error is greater than that of the no practice control the effect must be due to the presence of the visual cue.

Constant error

The difference between AIF practice results and no-practice results is clearer when constant rather than absolute mean error is used. Constant error means are very similar to AE for four out of the six conditions (see Fig 2). In the no-practice control

Figure 2 Absolute and constant error scores for test and retest for 4 AIF trained groups and no-practice and TIF trained controls.



group and the terminal feedback group subjects both under- and over- estimated the target so that group CE results are closer to zero than are AE results. There is little difference for all the AIF groups indicating that the subjects in these groups consistently overestimated the target pressure. If CE scores are used the mean no-practice results do not differ from the 50TIF results as very differing ranges produce similar means. In fact, all the TIF test scores lie between the negative and positive scores of the no-practice group. This difference was confirmed by a Wald-Wolfowitz runs test which was significant ($R = 3$ $p < 0.05$).

Comparisons between TIF subjects and those given 50 and 400 AIF trials indicated that the latter groups press harder than the required pressure, while terminal feedback subjects have very low CE scores. These differences were tested using the Mann-Whitney 'U' test and it was found that TIF subjects had smaller CE scores in test and retest than both AIF50, (test: $U = 10$ $p < 0.01$: retest: $U = 4$ $p < 0.001$), and AIF400 (test: $U = 6$ $p < 0.002$ retest: $U = 5$ $p < 0.001$).

Subjects who have no experience of the correct pressure on the bar tended to press over and under the target pressure, as did those subjects who had been trained using terminal feedback. Those subjects who received visual action information feedback consistently overestimated the pressure required. The effect of a short delay interval on this overestimation was quite remarkable, especially for the short practice conditions.

Variable error

Analysis of variable error was carried out because it was hoped that subjects would be less variable in their responses if they had a clearer idea of what was required of them (Adams & Goetz 1973). One way analyses of variance were performed on test and retest VE scores (table 15). The test analysis was significant but the retest was not. A trend analysis was performed on the test scores and this was significant ($p<0.05$), indicating that the variability of a subjects response decreases with increased amounts of AIF practice, and is least following TIF practice. Apart from the TIF condition this may only mean that increased amounts of practice do increase variability in responding, even without feedback (Seashore and Bavelas 1945, Newell 1974) but it may be that even when pressing too hard after 5 AIF trials subjects are more aware of what they are trying to achieve than are those who have no practice at all.

First test scores

As Annett (1970) has noted that "the typical first post AIF response was near the correct response" (p220), a Kruskal Wallis analysis of variance was carried out on these first scores (AE) and was significant ($H = 18.02$ $k = 5$ $p<0.01$). Inspection of the means (table 16) led to Mann-Whitney U tests being performed to compare group 6 with groups 4 and 5, and group 1 with groups 2 and 3. Both groups 4, (50AIF) and 5, (400AIF) differ from group 6 (50TIF) ($U = 11$ and 13 respectively $p<0.05$ in both cases). Neither 2, (2AIF) nor 3, (5AIF) differed from the no practice control group ($U = 27$ and 23 respectively). Of the 32 AIF trained

Table 15 VE: Means and Analyses: Test and retest.

A: Test

	1 NP	2 2AIF	3 5AIF	4 50AIF	5 400AIF	6 50TIF
Mean	4.45	4.12	3.19	2.68	2.03	1.73
S.D.	2.99	2.00	0.92	2.55	0.89	0.63

Analysis of test means

Source	DF	SS	MS	F	P
Practice conditions	5	4.844	9.69	2.70*	*
Within cell	42	150.58	3.59		
Total	47	199.02			

B: Retest

	1 NP	2 2AIF	3 5AIF	4 50AIF	5 400AIF	6 50TIF
Mean	3.59	3.44	3.25	2.58	2.35	2.40
S.D.	1.77	1.17	1.85	1.14	0.54	0.75

Analysis of retest means

Source	DF	SS	MS	F	P
Practice conditions	5	12.33	2.47	1.28	NS
Within cell	42	81.27	1.94		
Total	47	93.61			

Table 16 AE: Mean first test score for six groups.

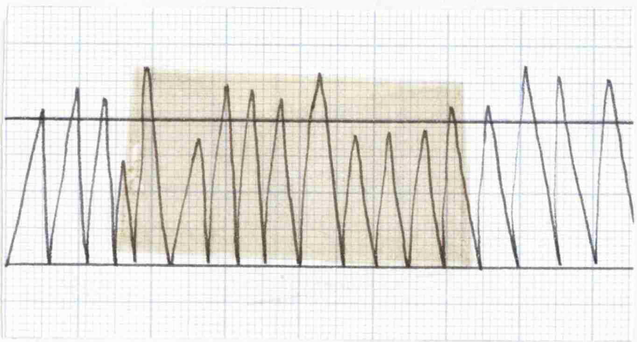
	1 N.P.	2 AIF2	3 AIF5	4 AIF50	5 AIF400	6 TIF50
Mean	8.62	11.19	6.50	5.44	4.25	1.00
S.D.	4.65	7.48	5.12	4.17	2.68	1.34
Range	3-18	3-27	0-13	0.5-10.5	1-8	0-3

subjects tested 6 gave first test responses   1 error unit from the target, 6 of the 8 TIF subjects also did this. The claim that the first post AIF response was typically near the target was not substantiated in this experiment.

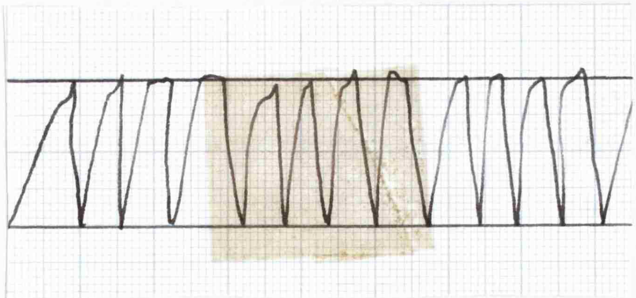
Response style

During practice AIF and TIF subjects responded differently. AIF subjects tended to push the bar first in a rapid movement and then they slowly increase pressure until the target is reached. TIF subjects make smooth continuous movements (see fig 3). This suggests that feedback control is very important in AIF controlled movement rather than in TIF, in the ways described by Woodworth (1899), Vince (1948) and Keele (1968). If no 'homing' part of the response can be detected in TIF trained subjects it may indicate that their movement is not in fact feedback controlled.

Fig. 3. Examples of typical AIF and TIF practice styles, showing "homing" movements with AIF.



Typical TIF practice



Typical AIF practice

Discussion

Although the differences between minimal or no-practice groups and those with a considerable amount of AIF practice were not clear cut, the indications from this study are that a very small amount of AIF practice is detrimental to the learning of this task. AIF training with 50 or 400 trials was not as good as TIF training with 50 trials, but it was better than no training at all.

Differences between the conditions were obscured by the large within group variation in some conditions. Some subjects in the longer AIF practice conditions made a disproportionate amount of the error, suggesting that individual differences in dependence upon the visual cue may have a considerable effect on the way in which subjects respond to such training. It is also likely that some AIF subjects used the visual cue as if it were terminal feedback by looking away from the display until the movement was complete.

The constant error scores bear out Annett's (1970) statement that AIF subjects consistently overestimate the target pressure. This is especially so for the 2 and 5 trial AIF groups after a rest interval. The extreme error shown by these groups is consistent - most subjects appeared to feel that the bar must be pressed exceedingly hard, presumably because they had remembered the magnified visual information and forgotten the 'feel' of the response to be made. The visual cue seemed to have distorted subjects' view of what the task was, that is, their central percept about it, as well as their perception of the kinaesthetic feedback. AIF trained subjects given a few practice trials, were more consistent than those who had no practice at all. They were aiming for something more clearly defined, even if it was very wrong.

The results after a few AIF trials were contrary to what might be expected on the basis of guidance studies, and to the findings of Fox and Levy (1969). The crucial element may be the transformation from the task to the display. After a little AIF practice subjects made large errors - they had attended only to the visual cues. The decrease in overestimation found with 50 or more AIF trials may indicate that the relative roles of visual and kinaesthetic feedback have changed (Fleishman and Rich 1963). Those subjects who make large errors after 50 or more such trials may be very visually dependent and unable to transfer to a kinaesthetic mode of control. As TIF subjects appear to press the bar in one 'pre-preprogrammed' movement the dependence on feedback will be much less.

A continuous visual cue is useful in acquiring a pressing response although many more trials are necessary than with terminal feedback. From the point of view of training the task/display gain may be most important but most subjects can learn the task very accurately with AIF. From a theoretical perspective, however, it is obviously important that even after extensive training AIF subjects consistently over-estimate the target pressure while TIF subjects bracket the target. The visual cue exerts an influence even when the task is quite well learned.

4.5. Experiment 3: Speed and accuracy of AIF practice.

Introduction

Method

Subjects

Apparatus

Procedure

Results

Absolute error

Constant error

Error in practice

Confidence ratings

Discussion

Introduction

Many subjects who were trained by AIF in previous experiments made practice movements with at least two stages - an initial fast one and a second homing one - while a few AIF subjects and most TIF subjects made single movements. Method and speed of practice may affect the accuracy of retention which can be achieved with AIF practice. AIF subjects take considerable time over their practice movements while TIF subjects do not, so that they have more than enough response-produced feedback and actually too much information about the task.

Annett (1959), in one study, required subjects to tap a bar rather than move it slowly. These subjects were almost as accurate after AIF practice as after TIF practice. Annett does not give any information about the errors found in practice and these could be important. Subjects pressing at their own speed can be very accurate with visual feedback, perhaps too accurate.

Although accurate practice need not prevent learning (Adams 1971), if a movement pattern is stored as a 'schema' instance which has been error labelled using knowledge of results (Pew 1974, Schmidt 1975), a modal value of the correct movement is built up using experience of error, i.e. by allowing the subject to make active choices (Welford 1968). Thus AIF practice in which the subject was prevented from making very accurate feedback controlled homing movements but in which practice was more accurate than in TIF training, should produce better retention than unpaced AIF practice.

This experiment duplicates some of the features of Annett's (1959) study. An auditory cue was used to regulate the time of the subjects pressing - either once every 4 seconds or once every 0.3 seconds. Only the slower rate was used with terminal feedback as it was impossible to present this information at a faster rate.

Visual information cannot be used for correction of movement at movement times of less than 260 msecs. (Keele & Posner 1968). The fast practice condition in this experiment requires subjects to exert and release the pressure once every 300 msecs., which should allow some error correction although not a continuous monitoring of the display at the end of the movement such as is typical of self-paced AIF subjects. As the target remains the same for both conditions, performance in practice will be less accurate for the fast condition (Fitts and Peterson 1964).

It has been suggested by many investigators (e.g. Adams, 1971, Schmidt & White 1970, Schmidt 1975) that subjects obtain 'subjective reinforcement' from comparing expected and actual response-produced feedback, and that this enables them to judge the accuracy of their responses without knowledge of results. The use of confidence ratings was introduced in this experiment to investigate the expectations and evaluations of subjects trained by the different methods. The ratings suggested by Schmidt and White (1970) were used. These are : 1) a rating of S's confidence of being within 5% of the correct pressure (objective error confidence), 2) an estimate of actual error as a percentage of the target pressure (subjective error estimate), 3) direction of error, 4) a rating of S's confidence of the subjective error estimate being within 5% of actual error (subjective error confidence). It was expected that AIF subjects would be less confident when the visual cue was removed (Adams 1971). Although AIF subjects have had more experience of the correct kinaesthetic feedback from the task than do TIF trained subjects they can only make accurate estimates of error if this feedback has not been distorted by the additional visual cue.

As previous experiments have shown large individual differences in performance after AIF training a repeated measures design was used in this study. A retest after 24 hours on some subjects who had been given either 50 AIF trials or 50 TIF trials in experiment 2 indicated that there was little retention of the task after that time and the three conditions of this experiment were therefore run on successive days, so that each subject took part in each condition.

It was hypothesized that test results after fast AIF practice and TIF practice would be more accurate than those after slow AIF practice, although the fast AIF practice condition could be expected to show some influences of visual feedback control during practice.

Method

Subjects

Subjects were 9 members of the non-academic staff of Leicester University. Ages ranged from 21 to 43 years with a median of 25. There were 4 females and 5 males. None of the subjects had taken part in previous experiments using this apparatus.

Apparatus

The standard bar pressing apparatus was used with the addition of a tone generator controlled by a Camden process timer which produced a short tone over the subject's ear phones every 4 secs for the slow condition and every 300 msec for the fast condition.

Procedure

There were three conditions, in which every subject took part.

These were: AIF, with a trial every 300 msecs (AIF.F), AIF, with a trial every 4 seconds (AIF.S), and TIF, with a trial every 4 seconds (TIF.S). A fast TIF condition was physically impossible as subjects would have had to pause between trials to receive feedback and it would have been difficult to record the speed of the trial.

Presentation of each condition was balanced so that 3 subjects took part in each condition on the first day. Balancing was by three Latin square procedures so that three presentation of each condition occurred on each day. Subjects were randomly assigned to treatment order as they appeared on day 1.

AIF.F

Subjects in this condition heard a tone every 300 msecs through earphones. They were instructed as follows:

"Your task is to learn to exert a certain pressure on this bar. When you exert the correct pressure this dot will go from the bottom line to the top line. You will hear a repeated tone through the earphones, I want you to press each time you hear the tone. This will mean that you have to press quite fast. Do not be upset by the speed and remember that you are trying to learn the pressure. When you have practised for some time I will stop both the light and the tone. The light will be stationary in the middle of the display and you must then try to reproduce the pressure which you have been learning. I will warn you immediately before the light stops. You should continue pressing at your own speed, trying to reproduce the learned pressure. Let the dot return to the bottom each time after you have pressed the bar and try to keep your fingertips in approximately the same position on the bar".

As the instructions were being given E pressed the bar and showed that the light spot moved as described.

AIF.S

Subjects heard the tone at 4 sec. intervals and were instructed as follows:

"Your task is to learn to exert a certain pressure on this bar. When you exert the correct pressure this dot will go from the bottom line to the top one. You will hear a repeated tone through the earphones, I want you to press every time you hear the tone. When you have pressed for some time I will stop both the light and the tone. The light will remain stationary in the middle of the display and you must then try to reproduce the pressure which you have been learning. I will warn you immediately before the light stops, you should then carry on pressing at your own speed, trying to reproduce the correct pressure. Let the dot return to the bottom each time after you have pressed the bar, and try to keep your fingertips in approximately the same position for each trial". E again pressed the bar as the instructions were being given and showed that the light spot moved.

TIF.S

The tone was heard at 4 second intervals. Ss were instructed

"Your task is to learn to exert a certain pressure on this bar. You will hear a tone through these headphones, I want you to press each time you hear it. When you have released the bar I will tell you how close to the correct pressure you were. I will tell you "Too hard", "too soft", or "about right". Remember you are trying to learn the correct pressure. After some time practising in this way I will stop the tone and stop telling you how accurate you are. Then you must try to reproduce the correct pressure, at your own speed. Before the tone and information are stopped I will warn you. Let the dot return to the bottom each time after you have pressed the bar, and try to keep your fingertips in approximately the same position for each trial."

TIF subjects were told 'too hard', 'too soft', or 'about right' after each response, with an accuracy of $\pm$ 0.5 units from the target being required for the 'about right' feedback.

After 30 practice trials all conditions had 10 test trials with no feedback. Subjects then completed a confidence rating questionnaire and the experimenter made conversation until 2 minutes had elapsed from the end of test and subjects were retested. The ratings were also made after retest.

The rating scales were:

1) rating on a scale from 1 to 5 of objective error confidence,
2) subjective error estimate,
3) direction of error,
4) rating on a 1 to 5 scale of subjective error confidence.

In general subjects were warned repeatedly that the task would be tested without feedback, especially on day 1. In the slow conditions subjects were not required to use all of the 4 second interval to carry out one response, extra time was allowed so that subjects would not feel pressurised and they performed at their own pace within the 4 second limits.

Results

As all subjects contributed six scores to each analysis (test and retest for each of three conditions) absolute and constant mean error were analysed using 3-way analyses of variance with subjects as one factor and practice and test conditions as the other two. Interactions of subjects with other variables were used as error terms for the F test in each analysis.

Absolute error

Mean absolute error scores for test and retest, and the results of the analysis, are shown in Table 17. No differences were found between test and retest but the conditions of practice led to significantly different performance. The interaction of these two factors was not significant.

As differences between the conditions had been hypothesized further analyses were carried out which compared each condition with each other condition. These showed that results after AIF.F and TIF differed from those after AIF.S., while AIF.F and TIF results did not differ significantly. (see table 18).

Absolute error scores show no difference between the testing immediately after practice and after a short delay and type of training did not interact with the time of testing. This result might have been different had the time interval between test and retest been longer as performance deteriorated slightly less after TIF than it did after the other conditions. The significant difference between conditions is due to the AIF.S condition in which performance without feedback is worst.

Table 17a. AE: Mean scores for each of three conditions:

Test and retest

Test

	AIF.F	AIF.S.	TIF
Mean	4.26	8.03	3.14
S.D.	3.62	3.86	1.77
Range	0.5-	2.3-	0.9-
	10.35	16.2	6.2

Retest

	AIF.F	AIF.S	TIF
Mean	6.18	9.53	3.56
S.D.	5.80	4.91	2.28
Range	1.45-	3.65-	1.65-
	20.45	19.40	8.60

Table 17b. Analysis of the means in Table 17a

Source	SS	DF	MS	F	P
1 Test/retest	22.11	1	22.11	3.35	NS
2 Type of practice	274.00	2	137.00	10.15	*
3 Subjects	397.79	8	49.72		
1 x 3	52.71	8	6.59		
2 x 3	215.98	16	13.50		
1 x 2	5.43	2	2.71	0.503	NS
1 x 2 x 3	86.06	16	5.38		
Total	1054.07	53			

Table 18 Analyses of AE Means: Pairs of Conditions

AIF.F/AIF.S

Source	DF	SS	MS	F	P
1 Test/retest	1	26.35	26.35	2.95	NS
2 Practice Condition	1	114.13	114.13	11.11	*
3 Subjects	8	488.93	61.12		
1 x 3	8	71.35	8.92		
2 x 3	8	82.17	10.27		
1 x 2	1	0.40	0.40	0.07	NS
1 x 2 x 3	8	43.22	5.40		
Total	35	826.55			

AIF.F/TIF

Source	DF	SS	MS	F	P
1 Test/retest	1	12.31	12.31	2.01	NS
2 Practice Condition	1	31.45	31.45	2.035	NS
3 Subjects	8	238.34	29.79		
1 x 3	8	18.97	6.12		
2 x 3	8	123.57	15.45		
1 x 2	1	5.10	5.10	1.38	NS
1 x 2 x 3	8	29.60	3.70		
Total	35	489.34			

AIF.S/TIF

Source	DF	SS	MS	F	P
1 Test/retest	1	8.27	8.27	2.35	NS
2 Practice Conditions	1	265.42	265.42	17.96	**
3 Subjects	8	176.29	22.04		
1 x 3	8	28.13	3.52		
2 x 3	8	118.23	14.78		
1 x 2	1	2.64	2.64	0.375	NS
1 x 2 x 3	8	56.27	7.03		
Total	35	655.25			

Constant error

Constant error scores are shown together with AE in Figure 4. They indicate that after TIF training subjects again bracketed the target with over-and under-shoots, while the AIF conditions did not. An analysis of variance showed that conditions of practice were significantly different in their effects, but that time of test and the interaction of these two factors were not (table 19). No AIF.S subject had an overall negative constant mean error while one subject in the AIF.F condition underestimated. In the TIF condition there were 6 subjects who underestimated in test and 4 in retest.

Error in practice

The effect of speed of practice on practice error was investigated using absolute mean error in practice for each subject in each condition. AE scores for practice and test are shown in Figure 5. An analysis of variance with conditions of practice as one variable and test or practice as the other was performed. As was expected test and practice scores differed significantly as did conditions of practice, and the interaction between these two (table 20).

AIF.S subjects made fewer errors in practice and more in test than either of the other two groups and there is an interaction between practice and test scores - the more accurate the former, the less accurate the latter.

The low practice errors in the AIF.S condition were expected and would have been even lower had not one subject made quite large errors, apparently because the instructions had been misunderstood. As the subject had already successfully taken part in another condition the results were included.

Figure 4 Mean AE and CE scores for all conditions : Test and retest

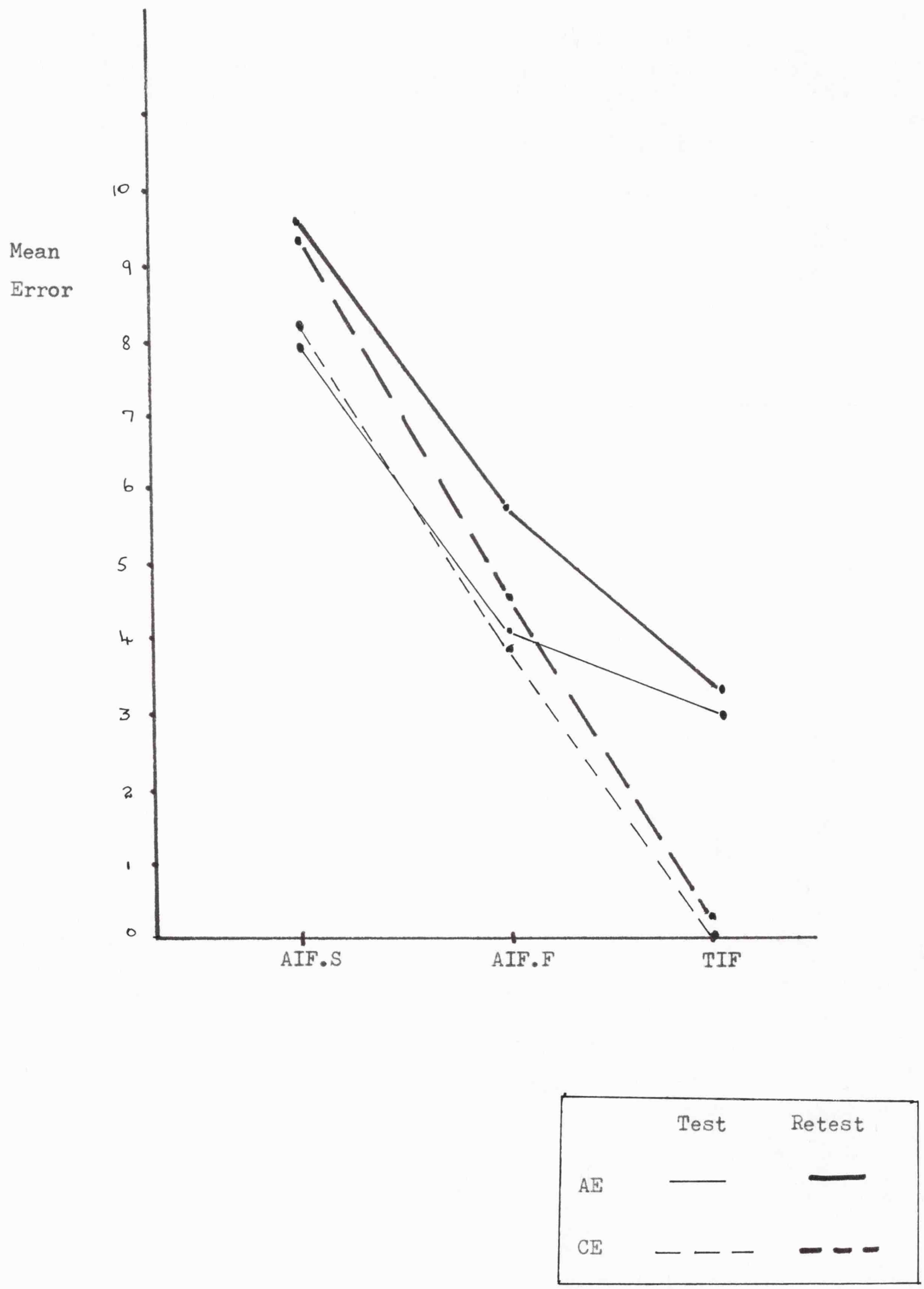


Table 19: Analysis of Mean CE Scores

Source	DF	SS	MS	F	P
1 Test/retest	1	5.54	5.54	0.41	NS
2 Type of practice	2	690.64	345.32	19.72	**
3 Subjects	8	557.8	68.725		
1 x 3	8	107.74	13.47		
2 x 3	16	280.23	17.51		
1 x 2	2	2.70	1.35	0.15	NS
1 x 2 x 3	16	141.74	8.86		
Total	53	1786.39			

Figure 5. Mean Absolute Error scores for all conditions: practice and test.

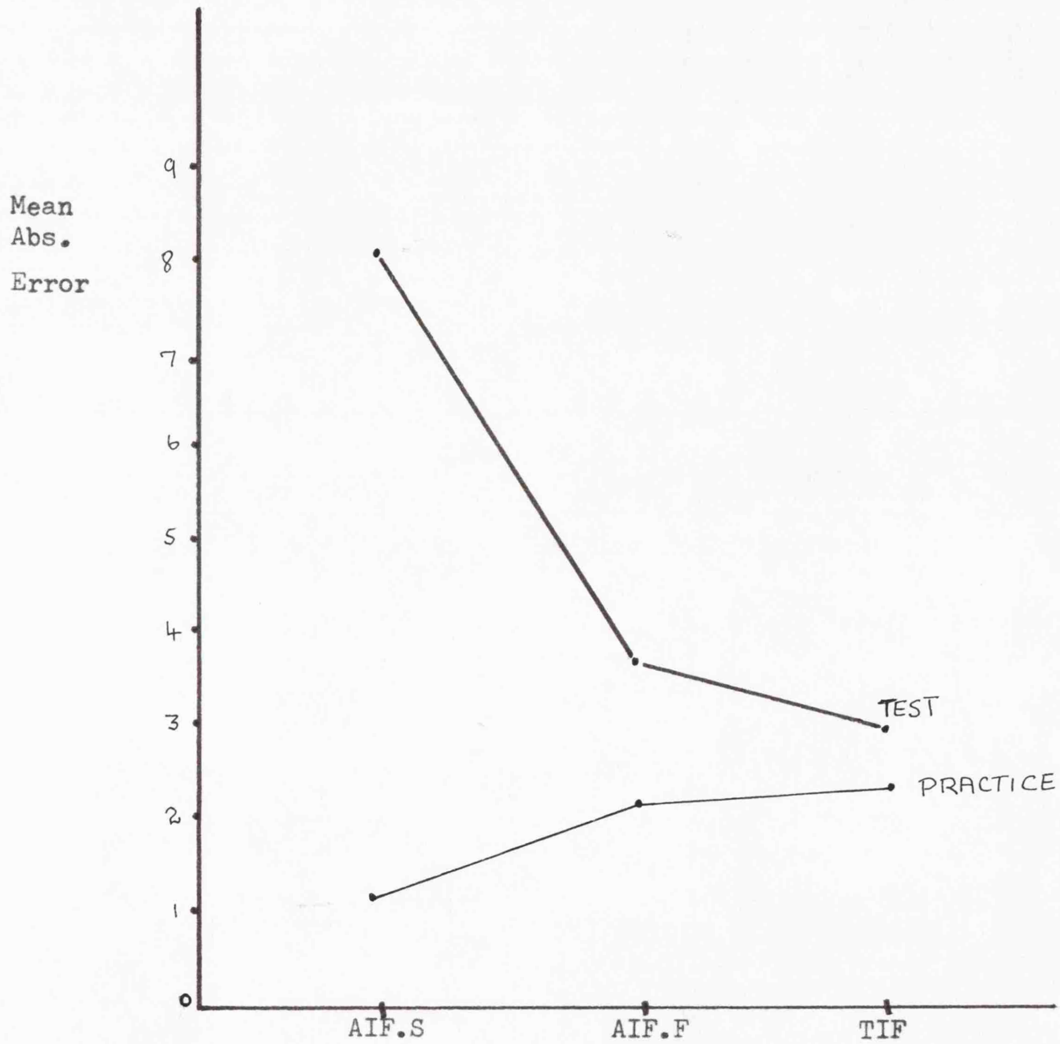


Table 20 Analysis of AE scores in Figure 4: practice and test

Source	DF	SS	MS	F	P
1 Practice/test	1	148.44	148.44	17.91	**
2 Conditions	2	32.24	16.12	4.97	*
3 Subjects	8	89.03	11.13		
1 x 3	8	66.31	8.29		
2 x 3	16	51.79	3.24		
1 x 2	2	94.08	47.04	10.03	**
1 x 2 x 3	16	75.11	4.69		
Total	53	556.99			

When practice scores are plotted in five-trial blocks (fig 6), it can be seen that subjects in the TIF condition make a large improvement in the first five trials while the AIF.F performance improves over trials as subjects learn to regulate the pressure which they exert. As expected the AIF.S condition shows little change over practice.

Confidence ratings

Analysis of confidence ratings and error estimation was not easy as the small numbers of subjects made chi squared tests inapplicable.

Objective error confidence ratings (in which subjects rated how sure they were that their results were within 5% of the target on a 5 point scale) are shown in Table 21. Ratings 1 and 2 (sure not) and 4 and 5 (sure were) were collapsed together. A χ^2 test for ratings by practice conditions after the 1st test was not significant ($\chi^2 = 3.73$). There was no difference in confidence between the conditions after the first test. A similar χ^2 of the objective error confidence ratings after retest was also not significant ($\chi^2 = 3.124$).

The mean percentage error scores given by subjects after test (subjective error score) are shown in Table 23, these were analysed using Friedman's 2-way analysis of variance. There was no significant difference between the conditions ($\chi^2 = 2.67$). The subjective error scores after retest were analysed in the same way and again there was no difference ($\chi^2 = 2.17$). However, when the discrepancy between the subjective error score (in per cent) and the objective error score (%) is analysed by the Friedman test there is no difference after test but one is found after retest.

Figure 6. Mean error per practice trial: in 5 trial blocks.

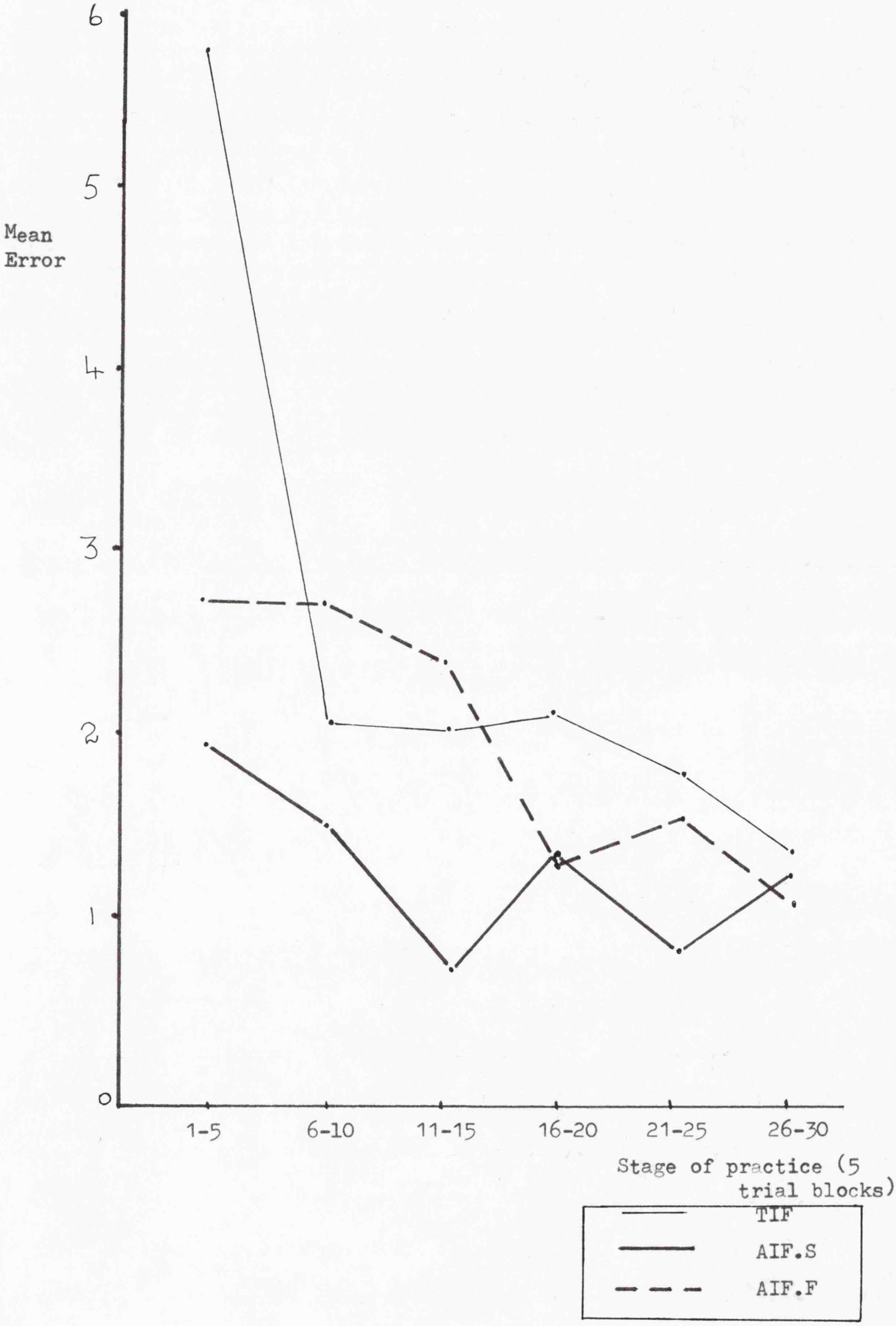


Table 21. Objective error confidence: rating of test performance as being within 5% of the target.

Test

	Sure not	Don't know	Sure were
AIF.F	6	2	1
AIF.S	5	1	3
TIF	4	2	3

Retest

	Sure not	Don't know	Sure were
AIF.F	5	1	3
AIF.S	6	2	1
TIF	4	3	2

Table 22. Subjective error confidence: rating of subjective error as being within 5% of actual error.

Test

	Sure not	Don't know	Sure were
AIF.F	2	3	4
AIF.S	2	1	6
TIF	1	3	5

Retest

	Sure not	Don't know	Sure were
AIF.F	4	1	4
AIF.S	3	3	3
TIF	2	3	4

Table 23 — Subjective errors: percent of target pressure

Test

	AIF.F	AIF.S	TIF.S
Mean	14.11	15.44	11.44
S.D.	10.94	10.40	8.03
Range	5 - 40	5 - 40	3 - 30

Retest

	AIF.F	AIF.S	TIF.S
Mean	11.00	14.22	12.78
S.D.	6.93	8.78	7.49
Range	5 - 25	5 - 30	5 - 30

(χ^2 = 0.72 and 8.67 respectively, the latter significant $p < 0.01$). This is due to the TIF condition in which subjects were more accurate in their estimates of error. While no condition gives more accurate estimation of error immediately after practice TIF training allows subjects to estimate their error more clearly after a lapse of time, even although they do not have increased confidence in their estimation (Subjective error confidence after retest, χ^2 = 2.43 N.S.)

This superior estimation of error is supported by the results of correlations between actual and estimated error within each group. (Table 24).

Table 24. Correlations between actual and estimated error: Spearman's rho.

	Test	Retest
AIF.F	-0.22	-0.025
AIF.S	0.29	0.35
TIF.S	0.50	0.54

None of these correlations reach significance but the TIF group is clearly more accurate in its estimations than the others.

These error and confidence ratings are difficult to use effectively. If subjects give a group rating for several results it is possible that some results will be close to the rating and some not, but as subjects in the fast condition kept responding at a considerable rate during test it was not possible to elicit an error rating for each response. As the conditions were performed by each subject it was possible for subjects to stick to the same rating each time rather than try to judge the accuracy of each test or retest trial. The subjective measures give suggestions only rather than positive findings but these are that the TIF training gives subjects a clearer idea of what constitutes accurate performance than does AIF training, even if this is not accompanied by increased confidence in the judgement made.

Discussion

These results confirm Annett's (1959) finding that learning to exert a certain pressure on a bar using a tapping movement leads to accurate performance when visual feedback is removed. Those subjects who pressed the bar once every 300 msecs did not actually tap but the movement involved was rapid and the visual cue could not be used for accurate monitoring of the response, although some error correction must have been possible. Had subjects in this condition received only visual terminal feedback the practice curve would be expected to resemble that for verbal terminal feedback more closely than it does, and over and under estimations of the target pressure would be expected in test.

The large differences in test and retest accuracy between the AIF.S and TIF conditions confirm the earlier findings that AIF practice is not equivalent to the same amount of TIF practice on this task. As these results are obtained from the same subjects the differences shown are quite striking.

Subjects in the AIF.S and TIF conditions did not all press slowly but performed at their own speed within the 4 second limits. This means that the speed component of successful TIF practice cannot be ruled out as a major element in learning the task, because TIF subjects typically press the bar in one quite fast movement. Again it appears to be the slow, monitoring, nature of the self-paced AIF practice which is detrimental to learning the task.

The short movement time in the AIF.F condition in this experiment is contaminated as a learning variable by the rate at which subjects were responding. Because subjects pressed and released the bar once every 300 msecs it was possible for them to develop a rhythm of movement over practice. Using a rhythm, with or without continuous feedback, may make such a pressing task easier by, for example, enabling subjects to count and achieve the correct movement by exerting a pressure for a regular period of time. On these grounds this experiment does not have directly comparable conditions. It is not clear whether the speed or the rhythm of movement is important for accurate learning of the pressure.

The issue is further complicated by practice error. If the accuracy of the response made with continuous feedback is a main cause of the lack of learning shown then the larger overall error found in practice in the AIF.F condition would also be expected to contribute to the improvement shown in learning. The detection and subsequent correction of error may be important for establishing a trace for the correct movement.

Subjects practising at their own speed with AIF do not determine the outcome of their movement before it occurs while those practising with TIF or with fast AIF may do so. Thus the memory trace or intention to perform the action cannot be updated - a programme for control cannot be made. This is not the same as the case of movement to a stop in which, although error is not made, the end of the action may be determined before it is begun. Self-paced AIF gives a subject little experience of error or of conscious error correction and prevents self-determination of movement. The magnified visual cue results in over estimation in test, probably because the size of the cue has persuaded subjects that the bar moves more easily than is actually the case. This overestimation is found in both AIF conditions indicating that some feedback control must be operating in the fast condition. The alternative explanation would be that a visual terminal feedback display with similar gain will also result in over pressing in test. This is unlikely but needs to be definitely excluded by a study of explicit terminal visual feedback.

The ratings given by subjects are not very informative. There is a suggestion that subjects who receive TIF, even of a non-specific type as in this experiment, are more able to evaluate their test performance than those in either AIF condition. It would perhaps have been more satisfactory if AIF.F ratings had been between the other two conditions in accuracy, as they were so in actual error. After AIF.F training subjects appear to have the subjective error estimation of a feedback controlled training, but the objective error does not bear this out in either practice or test.

Subjects under the illusion that the bar had become stiffer because their awareness of their kinaesthetic feedback had changed might be expected to estimate a too-heavy pressure as correct if they have in fact recognised that the bar appears stiffer. On the other hand, if they attempt to recreate the kinaesthetic feedback which they think they have received during training, they would underestimate the target and think that correct. As AIF trained subjects tend to overestimate the target, and to report that the bar has become stiffer, it is unlikely that they are attempting to recreate the 'feel' of correct movement, but are rather evaluating the feedback from the response, <u>after</u> the response has been made.

Subjective ratings are difficult to interpret at any time and the absence of significant results here merely postpones the problem. On the basis of the results found here it can only be suggested that subjects trained with terminal feedback develop a more efficient internal error detection mechanism than those trained with AIF. However, these subjects are also more accurate in responding in test so there is no evidence for a differential development of traces to initiate a response and to detect error. Active information feedback training produces subjects who are less accurate in both response production and error detection.

4.6 Experiment 4: AIF practice with a range of movement times

Introduction

Method

Subjects

Apparatus

Procedure

Results

AIF practice error: AE

AIF test error: AE

AIF and NIF test scores

NIF: displacement and variation

AIF and NIF results: relationships

Discussion

Introduction

In the last experiment it was found that pressing a bar with fast movements under conditions of action information feedback led to better retention of the target pressure than moving slowly in the same circumstances. This may not be due only to the speed of the individual movements but also to the rate of movement. This implies the existence of an interaction between the pressure exerted and the rate at which the movements are made. The experiment by Vince (1948) in which subjects made rapid movements to the tick of a metronome and attempted to stop the movement at a target also uses fast repeated movements in which the rate of repetition may be more important than the speed of individual movements. The Fitts' (1954) tapping task used to calculate the relationships of target size, movement distance, speed and accuracy requires subjects to tap as quickly as possible.

Speed of movement decreases as target area decreases or distance moved increases, and this has been interpreted by Keele (1968) in terms of feedback control of the terminal portion of the movement. If feedback control does operate on slow movements but not on fast ones then the distorting effect of the magnified visual cue should be greater as more time becomes available for feedback processing. Subjects forced to practice at a fast rate would however, show an inaccuracy in practice which might be more important for the building up of an accurate representation of the movement required. This all assumes that the other characteristics of the task do not interact with the actual rate of movement. Subjects may, for example, press harder at slower rates even when no feedback is available and learning is not taking place so that the results in test would not be wholly due to the type of feedback used in practice.

This experiment investigates the effect of practising with AIF at varying rates on the performance and retention of the bar pressing task. Subjects were also required to press the bar at each rate without any feedback at all. It was expected that faster rates with feedback would be less accurate in performance but show better retention when the feedback was removed than slower rates would. The no feedback conditions were exploratory and no firm hypotheses were held but it seemed likely that fast repeated movements would be more consistent than slow ones and possibly that less pressure would be exerted at fast rates.

Five rates of movement were used with those from Experiment 3 as the extremes. Every subject took part in all conditions on 5 successive days.

Method

Subjects

Subjects were 10 graduate and staff members of the department of psychology, University of Leicester. Ages ranged from 21 to 31 years with a median of 24. There were 5 males and 5 females.

Apparatus

The standard bar pressing apparatus was used. The tone generator and Camden timer were again used to produce tones at .3, .6, 1, 2 and 4 second intervals.

Procedure

To minimise sequence effects presentation of AIF rate and day of testing were balanced in a 5 x 5 latin square repeated twice. A second 5 x 5 latin square was superimposed on the first for presentation of the no feedback conditions with different rates of responding. The same speed was not presented to any subject in both AIF and NIF conditions on the same day. (Table 25)

Table 25. Order of presentation of conditions to subjects.

AIF

Ss	Days 1	2	3	4	5
1	.3	.6	1	2	4
2	.6	1	2	4	.3
3	1	2	4	.3	.6
4	2	4	.3	.6	1
5	4	.3	.6	1	2

NIF

Ss	Days 1	2	3	4	5
1	4	.3	.6	1	2
2	.3	.6	1	2	4
3	.6	1	2	4	.3
4	1	2	4	.3	.6
5	2	4	.3	.6	1

There were two parts to each experimental session:

1) NIF: subjects pressed the bar when they heard the tone in headphones. They were given no feedback of any kind, and made a total of 40 presses. Ss were instructed "In this part of the experiment you will hear a tone through the head phones. Each time you hear it press the bar.* That is all you have to do. The tone is a cue for you to press the bar. Keep pressing until I tell you to stop".

2) AIF: subjects pressed the bar when they heard the tone but attempted to learn the correct pressure using the visual cue on the oscilloscope. There were 30 practice trials and 10 test trials, subjects were warned that the cue was to be removed before this occurred. The 30 practice trial limit was retained from experiment 3 as subjects who had to press every 4 seconds became quite bored.

Subjects were instructed as in the NIF condition until * then "You are trying to learn to exert a certain pressure on this bar. When the light spot touches the top line you have exerted the correct pressure. Release the bar after each press sothat the initial position is the same for each movement. After you have practised for some time I will warn you and then stop the dot. You must then attempt to reproduce the pressure which you have been learning. Keep pressing until I tell you to stop"

Results

AIF results are shown in Table 26 and NIF results in Table 29. These results were analysed separately and together. Measures were : mean AIF practice and test scores (absolute error units), AIF practice in terms of displacement of the bar (displacement units), the mean of the first NIF scores in displacement units, and the mean of the last 10 NIF scores in both displacement and error units. The displacement units were used because subjects in the NIF conditions were not aiming for a target, and the variance of these movements is calculated in terms of the absolute displacement of the bar rather than around an arbitrary criterion.

AIF practice error: AE

Analysis of AIF practice errors indicated that there were differences between the five conditions (Table 27). A Newman-Keuls test showed that the fastest condition differed from all the others, and a Scheffé test showed that the 0.6 second and the 1 second conditions made errors which, when combined, were greater than those of the 2 and 4 second conditions combined ($p < 0.05$).

With 0.30 seconds in which to exert and release a pressure

Table 26 Summary of AIF results - mean and standard deviations

AIF test scores (AE) for five rates of movement

Rate	.3	.6	1	2	4
Mean	5.11	4.98	6.26	5.58	7.08
St. Dev.	3.02	3.43	3.34	2.63	3.43

AIF practice scores (AE) for five rates of movement

Rate	.3	.6	1	2	4
Mean	2.10	1.58	1.61	1.06	0.84
St. Dev.	0.70	0.43	0.72	0.60	0.35

AIF test scores (AE) for each of five days

Day	1	2	3	4	5
Mean	5.59	4.87	6.34	6.74	4.67
St.Dev	3.24	3.91	3.51	3.19	4.43

Table 27 — Anova summary and Newman-Keuls test: AIF practice error

ANOVA

Source	DF	SS	MS	F	P
1 Subjects	9	6.81			
2 Rate of Movement	4	9.82	2.46	8.79	**
1 x 2	36	9.93	0.28		
Total	49	26.56			

Newman Keuls test

Rate:	.30	.60	1	2	4
.30	-	4.86*	5.18*	10.40**	12.53**
.60		-	0.32	5.54	7.67*
1.00			-	5.22	7.35*
2.00				-	2.13

subjects make larger errors than they do at faster speeds but there is no constant improvement with increases in time of approximately 300 msecs. Practice errors are generally very small for all conditions, especially the slowest condition in which it averaged less than one error unit overall (table 26).

AIF test: AE Mean

Test scores were analysed separately in a one-way analysis of variance. This gave no significant results (see table 28).

Table 28 — Analysis of AIF test error

Source	DF	SS	MS	F	P
1) Rate of movement	4	30.32	7.58	1.10	NS
2) Subjects	9	265.24	29.47		
1 x 2	36	243.38	6.76		
Total	49	538.95			

A comparison of test scores of groups 1 and 5 (which had been found to differ in the previous experiment) repeated the previous finding ($t = 3.76$ $p < 0.01$). The improvement in test performance from the fastest to the slowest condition is not related to speed of practice in general but only to the extremes.

A Friedman 2-way analysis of the AIF test results by days rather than conditions was not significant ($\chi^2 = 5.30$). An interaction between days and treatments is not ruled out but with only 2 scores per cell it is difficult to test for it.

Table 29 — Error and displacement scores for five rates of movement, with no feedback during practice.

Summary of NIF results - means and standard deviations

a) NIF practice scores - displacement - for five rates of movement

Rate	.3	.6	1	2	4
Mean	27.42	27.39	26.14	26.63	31.36
St.Dev.	10.94	11.91	9.75	11.68	10.41

b) NIF practice scores - variation - for five rates of movement

Rate	.3	.6	1	2	4
Mean	3.99	3.02	3.29	3.22	3.12
St. Dev.	2.25	1.94	1.44	1.29	1.13

c) NIF test scores - error - for five rates of movement

Rate	.3	.6	1	2	4
Mean	9.83	10.71	7.74	12.24	13.28
St. Dev.	8.47	8.56	5.41	8.31	8.08

d) NIF practice scores - displacement - for five days of test

Day	1	2	3	4	5
Mean	30.98	26.59	26.07	28.33	26.95
St. Dev.	11.86	10.20	11.61	10.06	8.74

AIF and NIF test scores - differences.

The mean absolute error score for the final 10 trials in each NIF condition were compared with the AIF test scores (See table 30). AIF test error was found to be less than that in the corresponding 10 trials in the NIF conditions. The one press per second condition provides somewhat anomalous results in the NIF condition which may contribute to the lack of significance of the rate of movement factor (Fig.7).

NIF: displacement and variation.

NIF scores were analysed in order to discover which rates, if any, optimised the pressing task by causing subjects to respond at something near the target pressure, or which led to more consistent responding. A Friedman 2-way analysis on the mean NIF displacement scores for the first 30 trials was not significant ($X^2 = 6.80$). The mean displacement scores were also analysed by day of presentation. A Friedman 2-way analysis was not significant ($X^2 = 4.88$). The pressure exerted tended to be greater on the first day, but not significantly so.

Using subjects' standard deviation from the mean of 30 NIF practice trials as variable scores a 2-way Friedman analysis indicated that there was no difference in variation over the conditions. A similar analysis by days showed that although variation seemed greater on day 1, it was not significantly so ($X^2 = 1.98$).

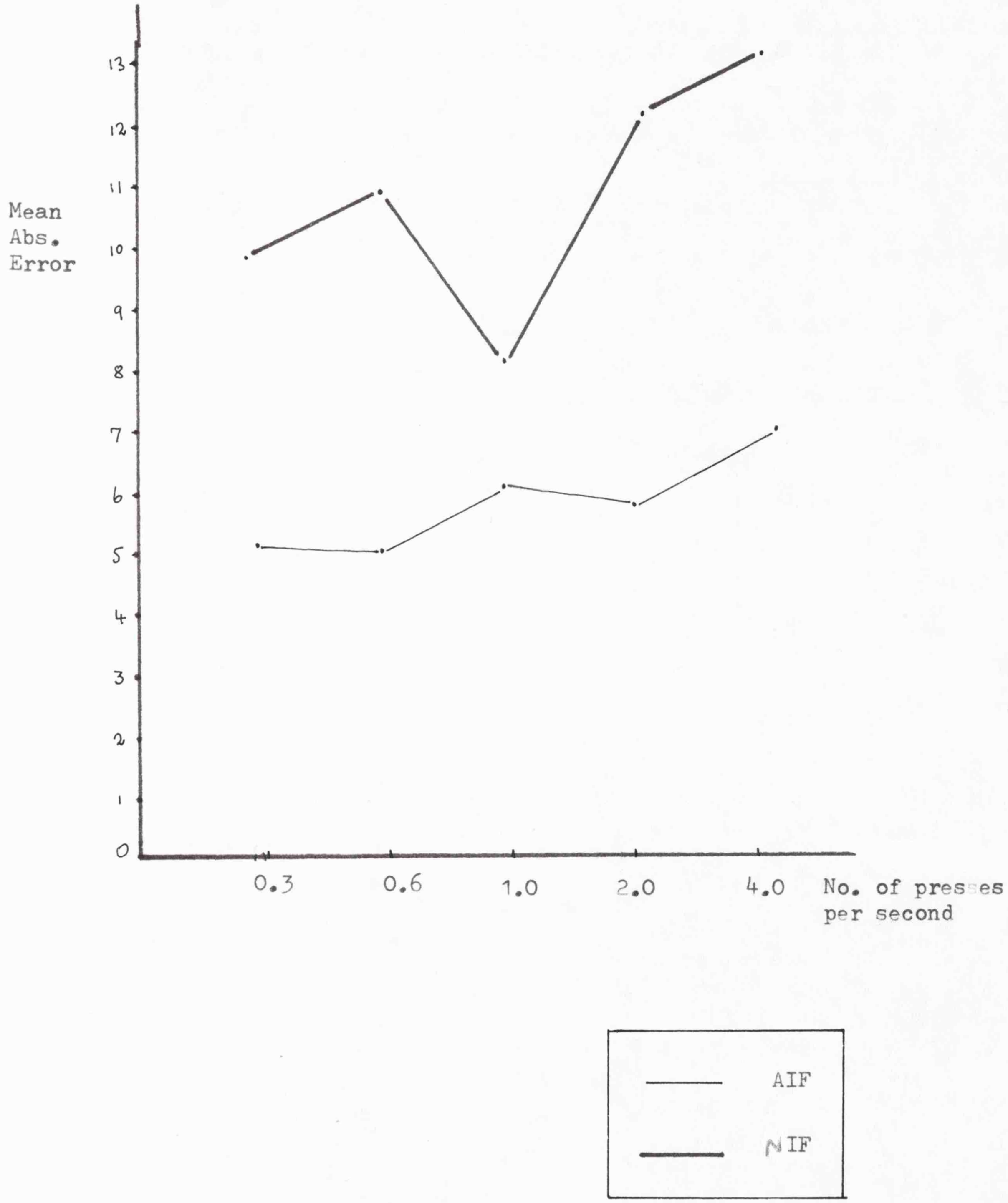
AIF and NIF results: relationships

Correlations coefficients were calculated on NIF displacement scores and AIF test scores for each condition and on NIF 'test' and AIF test error scores. These indicate that for the fastest

Table 30 Analysis: AIF/NIF test error

Source	DF	SS	MS	F	P
1 AIF/NIF	1	609.69	609.69	13.43	**
2 Rate of movement	4	128.87	32.22	1.14	NS
3 Subjects	9	1052.11	116.90		
1 x 3	9	408.59	45.40		
2 x 3	36	1019.21	28.31		
1 x 2	4	84.02	21.00	0.68	NS
1 x 2 x 3	36	1114.27	30.95		
Total	99	4416.77			

Figure 7 **AE Means of last 10 NIF trials and AIF test trials.**



rate of pressing (every 0.30 secs), which was the speed used in the previous experiment, there is a positive relationship between AIF test scores and pressure exerted under conditions of no feedback (see Table 31). Subjects may not be more accurate at this rate than they are in other conditions but their responses after training with AIF are related to those made with no feedback at all. Fast movements made at such a rate are not independent of that rate, regardless of the type of training received.

Table 31 Correlations between AIF and NIF scores for five conditions: Spearman's rho

AIF test (error) \ NIF	Speed .3	.6	1	2	4
AIF test (error) \ NIF practice (displacement)	0.84**	0.05	0.59*	-0.07	0.42
AIF test (error) \ NIF test (error)	0.71**	-0.46	0.38	0.10	0.53

Discussion

An increase in speed of practice does not lead to an increase in test accuracy after AIF training, although there are differences between the extreme speeds, nor does an increase in speed alter performance when no feedback is available. However, in one condition, the fastest of all, test accuracy and no-feedback performance are related. Subjects required to learn a pressure at a very fast rate may be influenced more by the rate than by other variables such as the type of feedback used. The conclusion of the previous experiment must be revised in the light of this finding as subjects' performance in the AIF test at a fast rate may not be due solely to the presence of visual cues.

It had been expected that the time available for feedback to be processed would alter subjects' dependence on the visual cue, but although practice becomes more accurate with longer intervals between trials, as would be expected on the basis of Keele's (1968) view of increasing numbers of feedback based corrections with increasing time, this was not strongly related to errors when the feedback was removed.

Practice is more accurate when 600 msecs rather than 300 msecs are available for the movement, presumably because more visual information can be utilised. However, control does not increase if a further interval of 300-400 msecs is allowed. That is, although the 300 and 600 msec conditions differ, it would be expected, on the basis of Keele's suggestions about the time required to make further corrections, that the accuracy of performance should change from 600 to 1000 msecs, which is not the case. No extra correction is made in the extended time, although it is possible at times of 2 seconds or over.

The distortion of kinaesthetic input by visual input is not related to the amount of time available for subjects to attend to the visual information, except that the test accuracy differed with the extremes of speed of pressing and it is in the extreme fast condition that the relationship between test accuracy and no feedback performance is found. Making repeated movements in such a way that the rhythm of movement becomes an important controlling factor affects the accuracy of movement with visual feedback and the accuracy of retention without it.

4.7 Experiment 5: Two sizes of control\display gain in visual AIF and TIF training.

Introduction

Method

Subjects

Apparatus

Procedure

Results

Absolute error

Constant error

Variable error

Subjective reports

Discussion

Introduction

In the preceding experiments only action information feedback could be given visually as the equipment available did not allow a terminal visual display. Thus, the magnification of display compared to movement which AIF subjects have experienced has not been controlled for by a similar visual input for the TIF subjects, and it is possible that this display gain factor may be more important than the temporal nature of the feedback. If the display gain is changed for AIF subjects while TIF remains verbal it is not possible to disentangle the effects of changes in visual display from the cueing or guiding properties of AIF.

Annett (1970) has reported that short movements result in proportionately greater overestimations after AIF training than do larger movements, and that large gain results in greater overestimation than small gain. If this is so, then the bar pressing task used in the earlier experiments, in which there is a very large gain (1:15) and a very small movement (3 mm), would be expected to lead to overestimation of the target when AIF is removed. Reducing the gain factor by half (i.e. to 1:7.5) should result in less overshooting if the distance moved is kept constant.

The only reported finding on the topic of movement and gain size in AIF training is that of Annett (1970). He puts forward an intersensory hypothesis which suggests a straight-forward summation of visual and kinaesthetic information. This means that if the relationship between kinaesthetic and visual information is changed there should also be changes in the size of the overestimations produced when feedback is removed. Annett does not consider the effect of practice on the relationship between movement size and gain, and,as his experiment allowed only 10 practice trials the effects of a large visual display may be exaggerated (see Experiment 2).

There is no evidence as to the effect of display gain on visual TIF, and it is obviously necessary to include TIF conditions. The availability of a Dec PDP Lab 8E computer with an oscilloscope to provide immediate display meant that both types of feedback could be given visually and that the same bar could be used so that results would be comparable with those from previous experiments.

Reduction of movement-display gain may also affect subjects' opinions of their accuracy under test conditions. In general AIF subjects may be making what they believe to be the correct response, but actually pressing too hard because of the extent of the visual cue with which they have been trained. This would mean that AIF subjects in both large and small gain conditions should be confident of the accuracy of their performance, but report a change in the characteristics of the apparatus. There should be less perceived change in the apparatus in the small gain condition. The results of Experiment 3 have indicated a general lack of confidence in their test performance by AIF subjects, in what are, in fact, erroneous responses. If these subjects also feel that the bar has become stiffer then neither the basic programme or memory trace, nor the sensory trace has developed adequately.

In this experiment both accuracy and increased stiffness ratings were used in order to investigate the relationship, if any, between gain of display and perceived post-practice stiffness, and between stiffness and subjective estimates of accuracy. There were four independent conditions, two receiving TIF, and two AIF training. One group from each feedback condition had a movement-display gain of 1:15 while the remaining groups had a gain of 1:7.5. The four conditions were labelled: TIF.L (large), AIF.L, TIF.S (small), and AIF.S. It was expected that AIF subjects would make more error in test than TIF subjects and that those in the AIF.L condition would overestimate more than those in the AIF.S condition.

Method

Subjects

Ss were 40 undergraduate and post graduate students of the University of Leicester. There were 20 males and 20 females. Ages ranged from 19-25 years with a median of 21 years.

Apparatus

The standard bar pressing equipment was used except for the oscilloscope and pen recorder. These were replaced by a PDP 8 Lab E computer which was programmed to control the display and record the movement made. The output from the strain guage bridge was fed into the Devices polygraph and amplified. This output was then fed into the computer.

The computer was programmed to display two horizontal marks 5mm long on the screen. The lower of these was 4 cms from the bottom of the screen and for the large gain conditions the upper mark was 4.5 cms above this while for the small gain conditions it was 2.25 cms above. In the AIF conditions an increase in voltage above the resting level from the bridge caused light spots to appear on the screen in a line perpendicular to the horizontal marks. The voltage change caused by exertion of the correct pressure caused the line of dots to reach the top mark. Greater pressure than this caused the line to overshoot the top line. In this condition overshoots could be recognised but not corrected once they had been made. A decrease in voltage indicated that the trial was terminated.

Thus subjects in the AIF condition saw a line grow on the screen as they pressed the bar and they were required to stop pressing when the line reached the target mark.

In the TIF condition the two cue marks were visible on the screen while the subjects pressed. When the pressure was released a line appeared on the screen beginning at and perpendicular to, the lower horizontal mark. This showed how close to the target the previous trial had been.

Procedure

Subjects were randomly assigned to one of the four conditions with equal numbers of males and females in each group.

Each subject was seated in front of the computer oscilloscope with the bar on the preferred side. All subjects were given two trials with feedback and then 5 without. This was followed by the main practice session of 30 trials followed by 5 test trials.

In the AIF groups the feedback appeared as the subject pressed and when the pressure was released it remained on the screen for 1 second. Following this there was an interval of 1 second before the cue marks appeared. Subjects could respond at any time after the appearance of the cue marks. In the TIF condition no feedback was given during trials but it appeared when the trial ended and remained on the screen for 1 second. The interval between the removal of the feedback and the re-appearance of the cue marks was again 1 sec. All subjects were warned that feedback was to be removed and the teletype printed a nonsense message after the final practice trial, the sound of which indicated that test trials were beginning. This sound was also heard after the initial 2 trials and the 5 pre-test trials so that subjects were accustomed to it when practice ended.

After test subjects were asked to rate the change in stiffness of the bar when the feedback was removed, on a five point scale from (1) 'much less stiff' to (5) 'much stiffer', with (3) being 'the same'. They were also asked to estimate their test performance on a five point scale from (1) 'very inaccurate' to (5) 'very accurate'.

Subjects were instructed as follows:

AIF

"In this experiment your task is to learn to exert a certain pressure on this bar. * When you press the bar a line will appear on the screen starting at the bottom mark, this line becomes longer as you press harder and when it touches the top mark you have exerted the correct pressure. When this happens release the pressure and wait for the two marks to reappear on the screen before trying again. If you press too hard you will overshoot the top mark, if you don't press hard enough you will not reach it. * Try it ... now try again ... (two feedback trials). Now I want you to try to reproduce the correct pressure as accurately as possible. The line will not appear - just press to what you think is the correct pressure, release the bar, and wait for the cue marks to appear before trying again. Keep doing this until I tell you to stop. (Five pre-test trials).

Now you are going to learn the pressure. ** Each time you press the line will appear, try to learn what the pressure feels like when the line reaches the top mark. ** After you have practised for quite a long time the line will no longer appear and you will then have to reproduce the pressure as accurately as possible. The teletype will make the noise it made earlier when you have practised long enough and after that the line will not appear.

Remember that you are trying to learn to exert the pressure without the visual cue.

(After 30 practice trials E said:)

Now the line will not appear. Try to remember the correct pressure".

TIF

As AIF except between * and *, and between ** and **.

* "When you have pressed the bar to what you think is the correct pressure and then released it a line will appear on the screen starting from the bottom mark. This tells you how accurate you have been. If the line reaches the top mark you have exerted the correct pressure, if it overshoots it you have pressed too hard, and if it does not reach the mark you have not pressed hard enough. Wait for the two marks to reappear then try again."

** "Each time you press the line will appear when you have released the pressure. Try to learn what it feels like to exert the pressure which makes the line touch the top mark."

Results

Results were calculated as percentage error for each trial. Mean scores for absolute, constant, and variable error were found for each of the conditions for each subject, and those for the pre-test, practice and test were analysed.

Absolute error

Mean absolute error scores are presented in Figure 8, and further information and the results of a 2 x 2 x 3 analysis of variance are shown in Table 32. No differences were found between small and large gain or between AIF and TIF but the stages of learning differed, and the stage/feedback interaction was significant.

Figure 8. **AE for two types for feedback training and two types of display gain.**

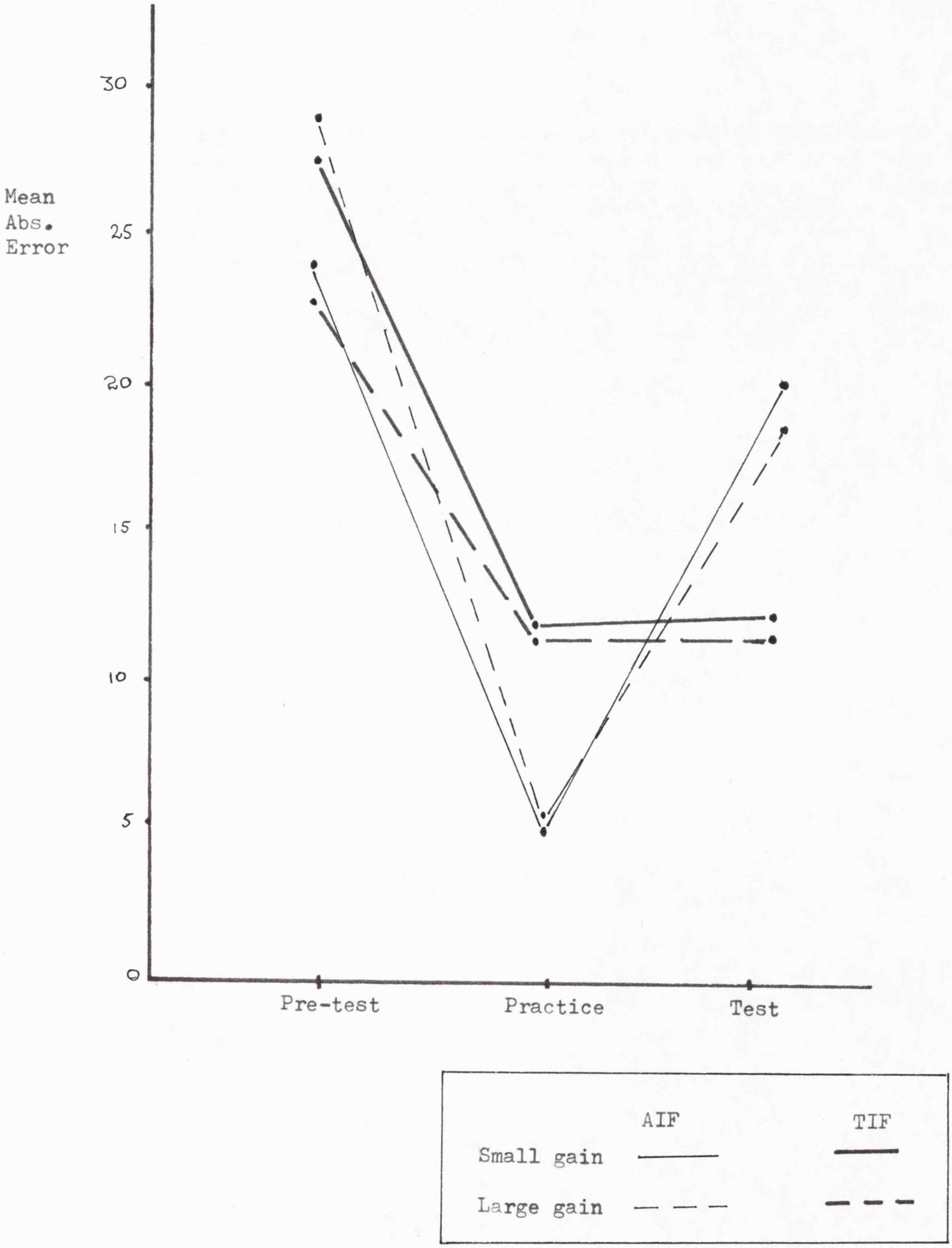


Table 32 Standard deviations of the AE means in Figure 7 and the results of an analysis of those means

		Pre-test	Practice	Test
AIF.S	S.D.	13.07	1.37	14.12
	Range	6.57-42.77	2.87-6.80	5.31-38.95
AIF.L	S.D.	12.77	2.25	12.15
	Range	5.71-43.90	2.73-9.34	4.95-36.24
TIF.S	S.D.	10.55	1.46	5.17
	Range	11.80-39.43	9.65-13.87	3.96-21.24
TIF.L	S.D.	11.54	1.18	5.12
	Range	7.83-45.28	9.13-13.36	6.07-23.42

Analysis

Source	DF	SS	MS	F	P
Between					
1) Gain	1	5.24	5.24	0.05	NS
2) Feedback	1	6.17	6.17	0.06	NS
1 x 2	1	53.95	53.95	0.48	NS
Ss within groups	36	4031.41	111.98		
Within					
3) Stage of learning	2	5691.98	2845.99	35.36	**
1 x 3	2	23.10	11.55	0.14	NS
2 x 3	2	915.10	457.55	5.68	**
1 x 2 x 3	2	171.15	85.58	1.06	NS
3 x Ss x groups	72	5795.20	80.49		

As can be seen in Fig 8 there are differences between the two feedback conditions in practice and test and these were investigated in a main effects analysis of the interaction of stage of learning and feedback (Table 33). It was found that the feedback conditions differed at practice and test but not in pre-test. Subjects trained with AIF are more accurate in practice but not as accurate in test as those trained with TIF. This confirms previous findings with verbal TIF.

Constant error

Mean constant error for each type of feedback, gain, and learning stage, is presented in Table 34. A 3-way analysis of variance showed that conditions of feedback differed as did the stages of learning but there was no difference between large and small display gain (Table 35).

Fig. 9 shows the overall AIF and TIF means for the three stages in both absolute and constant error. TIF subjects press above and below the target after 2 trials while AIF subjects tend to overestimate the pressure required even at this stage, as was indicated in Experiment 2. This is confirmed by a 3-way Anova with gain, feedback type, and first or second test as the factors. In this analysis AIF and TIF results differ although the two test conditions do not (see Table 36). This suggests that differences between first and second test scores cannot be used, as after only two familiarisation trials AIF and TIF subjects differ in the way in which they perform. TIF subjects, although their absolute error score is high, tend to underestimate the required pressure more often than do AIF subjects.

Table 33 Analysis of main effects in interaction between stage of learning and type of feedback in Table 31.

Source	DF	SS	MS	F	P
Feedback at pre-test	1	18.77	18.77	0.21	NS
Feedback at practice	1	452.26	452.26	4.97	*
Feedback at test	1	450.24	450.24	4.95	*
+Pooled Error	108	9826.61	90.98		

+Pooled error = $\frac{\text{Ss within gps} + 3 \times \text{Ss within gps}}{pr(n-1)+pr(n-1)(q-1)}$

Table 34 Mean constant error (percent): all conditions

AIF: small gain

	Pre-test	Practice	Test
Mean	13.81	-2.10	14.53
S.D.	19.73	2.59	18.36
Range	-14.96-	-5.54-	-9.62-
	42.77	1.98	43.48

AIF: large gain

	Pre-test	Practice	Test
Mean	22.34	-1.64	14.48
S.D.	19.28	1.84	14.67
Range	-17.22-	-4.53-	-8.52-
	43.90	1.72	36.24

TIF: small gain

	Pre-test	Practice	Test
Mean	2.11	-0.76	-4.49
S.D.	24.16	5.92	11.12
Range	-36.05-	-7.65-	-21.24-
	39.43	9.99	14.07

TIF: large gain

	Pre-test	Practice	Test
Mean	10.34	0.77	0.46
S.D.	22.67	4.39	9.54
Range	-30.36-	-6.47-	-22.95-
	45.28	6.62	12.96

Table 35 Analysis of CE Means in Table 33.

Source	DF	SS	MS	F	P
Between					
1 Gain	1	466.02	466.02	1.81	NS
2 Feedback	1	2341.19	2341.19	9.09	**
1 x 2	1	27.59	27.59	0.11	NS
Ss within groups	36	9270.04	257.50		
Within					
3	2	3435.70	1717.85	7.02	**
1 x 3	2	305.51	152.75	0.62	NS
2 x 3	2	1830.58	915.29	3.74	*
1 x 2 x 3	2	37.90	18.95	0.08	NS
3 x Ss x group	72	17630.07	244.86		
Total	119	35344.60			

Figure 9. Absolute and constant mean error scores for two types of feedback training.

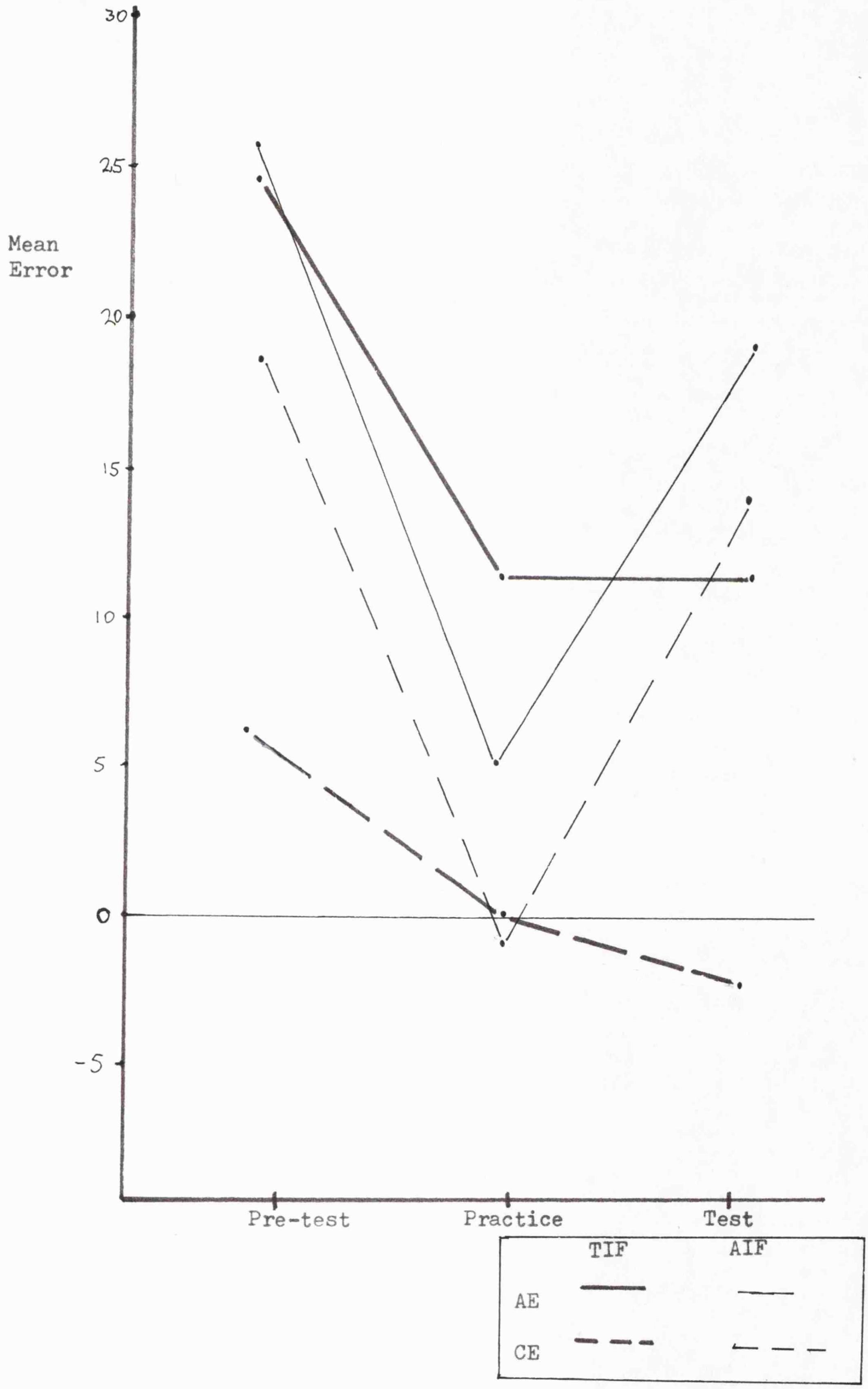


Table 36. Analysis of CE: pre-test and test

Source	DF	SS	MS	F	P
Between					
1 Gain	1	586.12	586.12	1.67	NS
2 Feedback	1	4027.12	4027.12	11.46	**
1 x 2	1	27.50	27.50	0.08	NS
Ss within groups	36	12647.30	351.31		
Within					
3 Pre-test/test	1	698.44	698.44	1.85	NS
1 x 3	1	175.47	175.47	0.46	NS
2 x 3	1	109.37	109.37	0.29	NS
1 x 2 x 3	1	35.17	35.17	0.09	NS
3 x Ss x group	36	13608.59	378.02		
Total	79	31915.08			

Variable error

Variable error scores are shown in Figure 10. These were also analysed in a three way Anova with feedback type, gain, and stages of learning as the factors (Table 37). No overall difference was found between large and small gain conditions but the feedback types differed, as did the stages at which performance was measured. The interaction between these two was also significant. AIF and TIF trained subjects are equally consistent in their pressing during test period, but, as is expected, TIF subjects show more variation in practice as they learn to correct error.

Subjective reports

i) Accuracy

In rating their test accuracy on a five point scale from 'very accurate' to 'very inaccurate' all subjects chose the middle three categories (see Table 38). One way X^2 tests were performed on ratings for AIF and TIF groups with an expected frequency of 6.67 for each cell. This was not significant for the AIF results (X^2 = 0.10), but for the TIF ratings X^2 was 7.60 which was significant ($p < 0.05$). AIF subjects are equally likely to choose any one of the three categories while TIF subjects use the 'inaccurate' category less often and the intermediate category most often, there is no difference in the use of the 'accurate' category.

If the accuracy ratings are combined by frequency of occurrence in the two gain conditions rather than the two conditions of feedback no differences are found (see Table 38b). No relationship was found between actual error scores (AE) and estimated accuracy (AIF: rho = -0.01, TIF: rho = 0.19).

Figure 10: **Mean Variable error for two types of feedback training.**

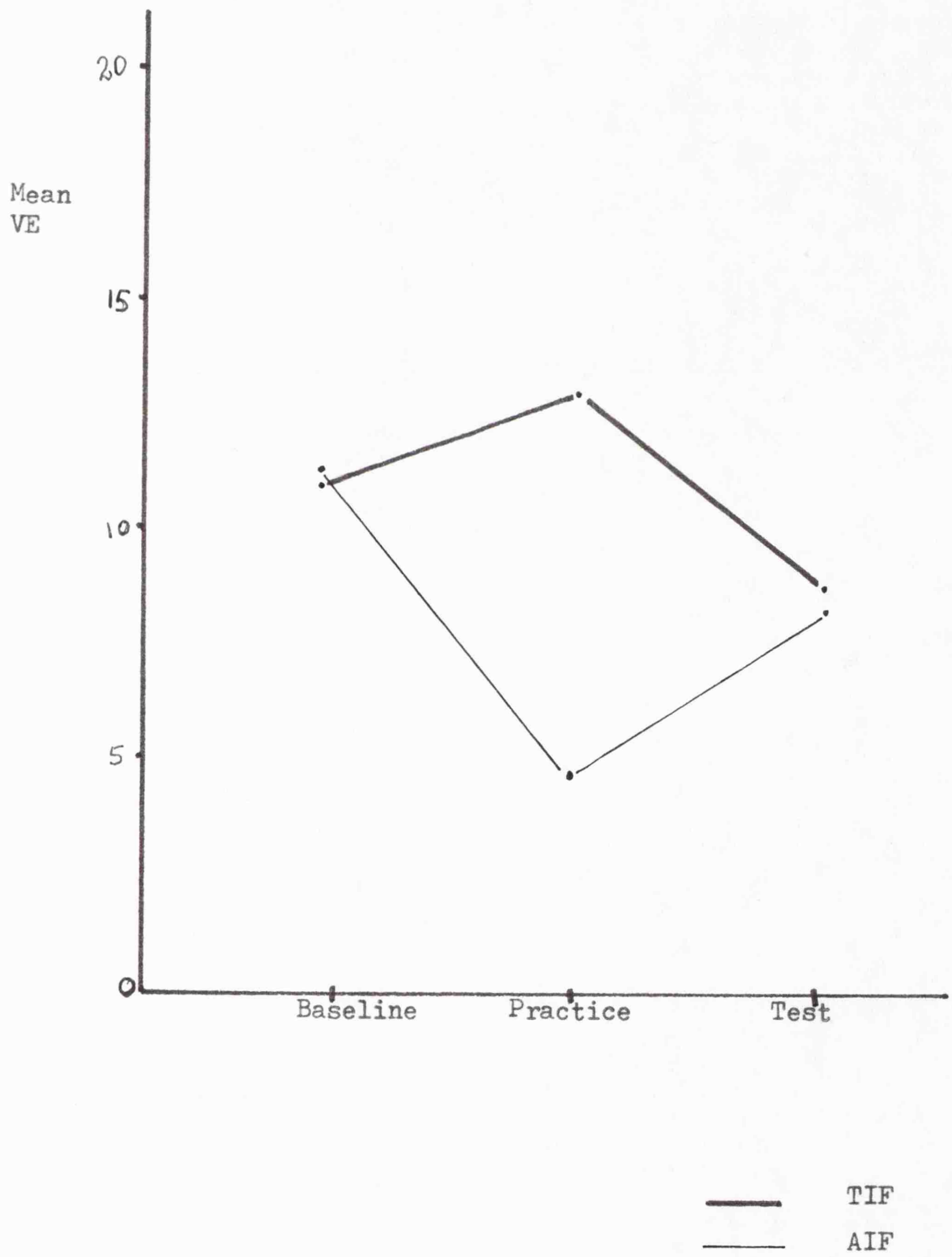


Table 37 Analysis of VE: all conditions

Source	DF	SS	MS	F
Between				
1 Gain	1	0.96	0.96	0.04
2 Feedback	1	258.07	258.07	12.08**
1 x 2	1	50.70	50.70	2.37
Ss within groups	36	769.39	21.37	
Within				
3 Stages	2	330.14	165.07	5.72**
1 x 3	2	145.28	72.64	2.52
2 x 3	2	478.24	239.12	8.28**
1 x 2 x 3	2	152.93	76.46	2.65
3 x Ss x group	72	2078.76	28.87	
Total	119	4264.48		

Table 38 Frequency of occurrence of accuracy ratings

A) Feedback types

Rating:	2 inaccurate	3	4 accurate	
AIF	7	7	6	20
TIF	2	12	6	20
	9	19	12	40

B) Display gain

Rating:	2 inaccurate	3	4 accurate	
Large gain	4	10	6	20
Small gain	5	9	6	20
	9	19	12	40

ii) Stiffness

For the increase of stiffness ratings with large and small gain conditions combined, only two subjects used the extreme categories and only one of the 40 subjects used either of the 'less stiff' categories, so the five categories were collapsed to two - 'not stiffer' and 'stiffer' (see table 39). A 2 x 2 chi^2 test on AIF and TIF totals for the two categories was significant ($X^2 = 7.29$ $p < 0.01$). TIF subjects felt that the bar remains the same while AIF subjects were more likely to believe that it had become stiffer.

As the gain variable was expected to be important in consideration of increased stiffness, the feedback conditions were also considered separately with respect to gain. Again categories were collapsed into 'not stiffer' and 'stiffer'. Subjects ratings of the increased stiffness of the bar during test did not vary between the two gain conditions within each feedback condition.

The relationship between the subjects' subjective error estimate and their increase of stiffness estimate was investigated using two categories only for each measure. These were 'stiffer' and 'not stiffer' for the increase of stiffness measure, and 'not definitely accurate' and 'accurate' for the accuracy estimate, that is, categories 1, 2 and 3 of both measures were collapsed together as were categories 4 and 5. (see table 40). The TIF results are dominated by the fact that 11 of the 20 subjects took the middle category in both cases. For the AIF results the observed tendency of subjects who were not definite about their accuracy to say that the bar was stiffer was tested by chi^2, and found not significant. ($X^2 = 0.62$). However, this tendency does indicate that AIF subjects do not think that they have performed accurately and interpret the different kinaesthetic feedback as evidence that the bar itself has changed, they are more likely to think that they have not been very

Table 39 Frequency of occurrence of ratings of increased stiffness.

AIF: two types of gain

	Rating: Not stiffer (1, 2 & 3)	Stiffer (4 & 5)	
Large gain	4	6	10
Small gain	5	5	10
AIF total	9	11	20

TIF: two types of gain

	Rating: Not stiffer (1, 2 & 3)	Stiffer (4 & 5)	
Large gain	9	1	10
Small gain	9	1	10
TIF total	18	2	20

Table 40 — Occurrence of stiffness increases and accuracy ratings

i) TIF

	Not stiffer (1, 2 & 3)	Stiffer (4 & 5)
Not definitely accurate (1, 2 & 3)	12	2
Accurate (4 & 5)	6	0

ii) AIF

	Not stiffer (1, 2 & 3)	Stiffer (4 & 5)
Not definitely accurate (1, 2 & 3)	5	9
Accurate	4	2

accurate <u>and</u> that the characteristics of the bar have changed.

Conclusion

The change of display gain from 1:15 to 1:7.5 in this experiment had no effect on subjects' performance after either action or terminal feedback. Subjects trained with AIF were more accurate in practice and less so in test than those trained with TIF. In test, AIF trained subjects press harder than the target pressure, while those trained with TIF over and under-estimated so that the difference between mean absolute and mean constant error is greater for the TIF than for the AIF conditions. Even after two practice trials AIF subjects tend to overestimate the pressure required while TIF subjects do not.

While most of these results were expected the lack of effect of the change in gain was not, and the result is contrary to the finding of Annett (1970), that overshooting increases with increased gain. The gain change also failed to make a difference in subjects' perceived increase in stiffness of the bar, although as only one subject used the extreme increase category the scale used may be too insensitive to detect a difference.

The stiffness and accuracy ratings indicate that the AIF trained subjects are equally likely to choose any one of the accuracy categories and more likely than TIF trained subjects to report that the bar is stiffer. TIF subjects feel that the bar has stayed the same and they have not been inaccurate. These results again are not unexpected, but it has been suggested earlier that AIF subjects might feel that they had performed accurately but that the bar had changed, when they had in fact pressed too hard. This was not the case. AIF subjects are less accurate, think themselves less accurate, and perceive the bar as stiffer than do TIF trained subjects.

Subjects given AIF training with a visual display overshoot the target, and feel the bar has become stiffer, than do those trained with a terminal visual display. These AIF subjects cannot be wholly trying to reproduce the sensory consequences which they have come to expect, because if they were they should rate their performance as accurate, overestimate, and rate the bar as stiffer. The effect of the continuous visual stimulus is not just to distract subjects from the kinaesthetic feedback, or to mingle with it so that it is classified wrongly, but to give subjects a false sense of security and lead to subjective feelings of inaccuracy as well as overshooting when it is removed. AIF trained subjects appear to believe that the bar moves more easily than it actually does so that they initiate a movement which is itself an over-estimate and then identify the resulting kinaesthetic feedback as due to changes in the bar itself.

4.8 Bar pressing and visual feedback: discussion

Continuous visual feedback provided during the learning of a bar pressing task leads to poorer retention of the task than does terminal feedback, whether visual or verbal. This supports the result of Annett (1959) but may be related specifically to this pressing task. As pressure cues are typically less informative than amplitude cues (Russell and Martenuik 1974, Weiss 1954) the information available from the kinaesthetic feedback during the task may well be swamped by the greater amount of concurrent visual feedback. If feedback evaluation is important for the reproduction of a movement then this could well lead to a decrement in performance when the visual cues are removed, but if it is the initial programming of the task which is affected, that is, if AIF prevents subjects from establishing a strong memory trace, the relative amounts of kinaesthetic feedback available should not be of such importance.

Some of the results found this far do indicate that the kinaesthetic feedback may not be as important for response production as Annett (1970) has suggested. If subjects are providing a measure of "what the original movement felt like" (Annett 1970 p. 220) they would presumably rate their performance as accurate, unless they had a poor opinion of their training as a standard by which to judge. In addition it is difficult to explain why the frequent estimations of increased stiffness in the bar itself should occur if subjects were reproducing the feel of the practice movements. The increased stiffness of the bar can only be explained by subjects having a programme which they use to produce the movement but which is not monitored completely and changed as it is used. The comparison between expected and actual kinaesthetic feedback appears to take place after the event. Thus the unaccustomed feedback resulting from the increased pressure exerted is translated into the results of the change in the bar itself. This discrepancy does not seem to be used to correct further test trials, i.e. subjects do not realise that they can reduce the stiffness of the bar by pressing less hard. They do not consider that they are being accurate even when the bar is stiffer. This may mean that some monitoring of the ongoing response takes place which leaves them unsure of the accuracy of their programme. TIF subjects on the other hand build up a more efficient error detection system even although the number of trials used in training is not enough for learning to have asymptoted.

While many of the AIF trained subjects made very large errors when the feedback was removed, some subjects were very accurate in test. The variances for AIF test scores are larger than for TIF test scores because of this. This suggests that individual differences in the amount of attention subjects pay to the visual cue could be quite large. Such differences may be similar to those exhibited by field dependent and field independent subjects (Pargman & Inomata 1976). That is, some subjects may be able to discount the visual cue and concentrate on kinaesthetic feedback more than others do. However, even if some subjects do perform accurately after AIF training, overall, most subjects overestimate the pressure required.

That a very small amount of AIF training causes large over-estimations of the target pressure while the same amount of TIF training results in both over and under-estimations was an unexpected result. Mechanical guidance studies and some visual guidance studies suggested that the first few trials were most useful as these reduce the initial uncertainty about the task. Again this finding may be exclusive to this task - the gain on the display appears to convince subjects that the bar moves quite a distance. This does not change significantly when the gain is halved, which would be expected if there were an intersensory control mechanism. However, in this case the visual deception may be of a rather crude quality. Annett's results were based on a maximum gain of 1:1.39 while the current experiment uses a minimum gain of 1:7.5. At this stage the large gain may simply represent a large movement with no subtle gradations.

The result of no difference between gain conditions after 30 practice trials is not so easily explained. Not only were there no actual differences in test but the subjects' ratings of their accuracy and the change in stiffness of the bar were also similar. This does not support an intersensory hypothesis in which vision and kinaesthesis are summed unless large gain can again be said to have crude effects only, giving visual perception of a large amount of movement, the actual size of which does not matter once the classification 'large' has been made.

The effect of AIF practice at high rates of movement is obscured by the relationships between rates and pressure exerted when no feedback is available. However subjects in the fastest condition used still overestimate the pressure during test although their absolute error is close to that after TIF training. This suggests that even at this speed there is an effect of the visual cue, which, while it may not guide performance, still convinces the subjects that the target pressure is greater than it actually is.

If TIF trials are typically fast while AIF trials are slow and accurate it is difficult to distinguish the effects of the type of feedback, the speed of the response and the accuracy of practice. TIF practice of a task which was of the same duration as AIF practice of the task may lead to similar retention when the feedback is removed, as subjects who perform slowly pay more attention to the feedback and may not learn as quickly as those who pay less attention to response-produced feedback and more to the achieving of the goal.

It is not clear why AIF training should lead to inferior retention although it is clear that it both affects retention and subjective judgement about the task. The issues of motor programme and feedback control are confused and sometimes seem untestable. Thus subjects trained with AIF may set up an inferior programme because of their dependence on the visual cue, or they may not reach the position of having an effective feedback trace because of the removal of one type of dominant feedback. It is also unclear whether subjects trained with AIF become better over practice because they have a more efficient programme or central control, or whether they learn to delegate control from vision to proprioception. The difference between 400 AIF trials and 50 TIF trials is not great in terms of absolute error but the AIF test results are overestimates which the TIF results are not. This indicates that even when the task is well learned using AIF the distorting effect of the large gain visual display is found. However it is not clear that this is due to the influence of visual feedback as a control process becoming less, rather than the influence of the visual cue on the initiation of responses.

Points of interest which will be followed up in later experiments are:

1: The speed of response. If the actual task is to make a movement in a certain time then both AIF and TIF subjects will be responding at approximately the same rate. If the task is to make a movement in a very fast time then the visual cue should not be of use as a cue to performance but should function as TIF.

2: For a task such as that mentioned above there is no natural gain factor. Time elapsed is only arbitrarily represented by visual displays. If the AIF effect prevails it will not be dependent on the intersensory confusion as much as on the visual dominance of the additional cue.

3: Attention to the visual cue as a distractor from other learning aids even when the cue is not necessary for accurate performance.

4: Comparison of performance after training with a mechanical stop, TIF and AIF. Two of these will give error free practice (comparatively) but only the AIF training uses an attention demanding visual cue. The mechanical stop condition would also not require decision making on the part of subjects and this comparison will make the role of the visual cue clearer.

Chapter 5

The effects of visual continuous feedback on the production and retention of timed movements.

5.1 The role of feedback in timing

In the previous experiments it was found that the time taken to execute a response and the accuracy of that response were related, as would be expected from findings such as that of Fitts and Peterson (1964). In addition, however, it seemed likely that the accuracy of practice in the AIF condition was due, at least in part, to the extra time taken to line up the display dot with the target so that accuracy of practice with AIF is confused with speed of practice with AIF. In an attempt to standardise the performance for subjects in all conditions a task was devised in which timing was the main component. Subjects were required to learn to move over a set distance in a specified time rather than learning to make a movement of a given size.

Skilled patterns of movement are very dependent on accurate timing of the integral parts of the sequence. Performing routines on the trampoline requires an athlete to time one part of a movement accurately so that the subsequent part can be initiated in the correct position.

As Michon (1967) puts it, it is "the fine structure of the timing between successive elements in a string of actions which characterises skilled performance" (p.1).

Most of the motor tasks which have been used to investigate timing have been those in which the subject uses information about the movement of a target gained from exteroceptors to predict the position of the target when a response is made, (e.g. when hitting a ball), or those in which the internal characteristics of the task can be learned so that the subject does not have to wait for a change to be perceived but anticipates this change, (e.g. sine wave tracking). Poulton (1957) calls these two types of anticipation 'receptor' and 'perceptual' anticipation the difference being than in the first the subject is dependent on exteroceptive feedback while in the second the trained subject uses internal cues.

The most obvious of the internal cues used in timing is probably counting, although Michon (1967) and Ellis (1969) have concluded that this is not sufficient for the timing of movement and that most of the evidence for its use is negative. It may be, however, that just as skill acquisition passes through a 'cognitive' (Fitts 1964) or 'verbal-motor' (Adams 1971) stage during which the learner exerts conscious control over what later becomes automatically executed, so in learning to time sequences of responses counting may be important early on in the acquisition although it is later phased out.

The mechanism which takes over control of a well timed interval may be non-cognitive and dependent on proprioception (Adams & Xhignesse 1960, Schmidt, 1969, 1971). Theories of proprioception as the mediator in motor response have been reviewed by Schmidt (1971) and by Jones (1973) and will not be reviewed here in detail. However, some anomalies arise from these two reviews, particularly that of Schmidt (1971), which cast doubt on the power of the proprioceptive control theory of timing.

The origins of ideas of proprioception as a timing mechanism appear to be based on anecdotes of musicians tapping while they play, and so generating proprioceptive feedback, and an experiment by Goldstone, Boardman and Lhamon (1958) in which subjects who counted aloud were found to estimate time better than those who counted silently, although this does not appear to be the most overwhelming evidence for the importance of proprioception as both auditory feedback and efferent signals were available.

Two main hypotheses about the role of proprioception in timing have been developed. These are the input hypothesis (Schmidt & Christina 1969) which says "that the subject uses the response-produced proprioceptive feedback from earlier portions of the response series as cues for initiating later responses" (Schmidt 1971 p. 385), and the decay hypothesis (Adams & Creamer 1962) which considers that proprioceptive feedback from a previous movement decays in a short term store and it is the course of this fading which mediates timing.

The differences between the two hypotheses have not been successfully tested experimentally (Cummings & Santa Maria 1974) but Schmidt (1971) concludes that nevertheless proprioception and timing are related, even if it is not clear how, on the basis of the work of Ellis, Schmidt & Wade (1968), Ellis (1969), Schmidt & Christina (1969), Christina (1970), and Quesada & Schmidt (1970), all of whom indicate that enhanced proprioceptive feedback from one movement facilitates subsequent timing.

Most of the movements in the studies cited above were active, so that a central mechanism for timing cannot be ruled out as, for example, increasing the loading on a handle not only changes the proprioceptive feedback but may actually change the response itself (Howard 1971). In addition Ellis (1970) found no improvement in time estimation after proprioceptive feedback, while Ellis et al.'s (1968) results contradict those of Adams and Creamer (1962), as the former study found that spring loading of a control made no difference to subsequent timing while the latter study found that it did. Schmidt and Christina's (1969) findings are unclear because subjects who made a medium sized movement with one hand were more accurate on a timing task performed with the other hand than were those who made either a small or a large movement before the timing task. A large movement would be presumed to generate more proprioceptive feedback and therefore should have led to more accurate timing.

Only Quesada and Schmidt (1970) found that feedback decay from a passive movement in one hand allowed subjects to improve their timing on a two second movement with the other hand after a total of 50 KR trials more than those subjects who watched a movement of the same size but received no proprioceptive feedback. However the non-movement group did improve their estimation of the time interval over practice. Learning to estimate time can be done even if there are no immediately previous movements.

One further study which concluded that proprioceptive feedback decay helped subsequent timing is that of Cummings & Santa Maria (1974) who used vestibular proprioception and compared the timing performance of subjects who had been rotated through 60 degrees with those who had not, and found that the rotated group were better. This study, however, might be explained by simple effects of experiment interest to subjects - being rotated is presumably an interesting experience.

Jones (1973) argued that most of the data presented by Schmidt (1971) did not rule out the possibility of motor outflow, although very little of the evidence from subjects deprived of proprioceptive feedback is related to timing rather than to spatial aspects of movement production (e.g. Taub & Berman 1968, Laszlo et al. 1970).

Unfortunately Schmidt (1973) argues that as subjects can estimate time accurately while using visual feedback i.e. watching a clock, they should be able to use proprioceptive feedback in the same way. There should be no difference between "having a subject watch a clock or having his limb moved predictably for 2.0 seconds" (Schmidt 1973 p. 390), as both provide reliable sensory information about the passage of time. This appears to beg the question of timing as subjects have to learn to relate the measurement of time from outside (i.e. clock time) before any internal timing by proprioception can occur. In addition, telling time by watching a clock is not time estimation at all. It is possible to perform amplitude movement tasks more accurately with visual feedback than with kinaesthetic or proprioceptive feedback alone. External calibration exists for one sense which does not exist for the other.

One important prerequisite of Schmidt's view of proprioception as timing is that the proprioception must be consistent over practice trials. This consistency was not provided in the study of Christina (1970) in which no effect of proprioceptive feedback was found. This appears to suggest that accurate timing of a second part of a movement will only be developed if the first part is performed consistently smoothly over practice, and that consistent performing of the first part and accurate timing of the second could not improve together. This seems implausible as an account of how accuracy in timing is actually learned.

Outside the field of timing of motor responses most theories of judgements of time assume that the perceived length of an interval depends on the information occurring during that interval (Thomas and Weaver 1975). This includes judging empty time intervals by subjective pulse rate (Treisman 1963), and occasions when discrete items fill an interval, when the number of discrete events is related to perceived length of time (Ornstein 1969), although familiarity of stimuli may be inversly related to perceived duration (Avant, Lyman and Antes 1975).

It is not clear how such theories about temporal judgements relate to theories of timing motor responses. None of the studies are interested in subjects learning to estimate time during movement, and as learning to time response B correctly when it follows response A may have no relationship to subjects' abilities to estimate 'clock' time it is not clear how a relationship can be shown. However, the general assumption that temporal judgements are related to the content of the intervals fits the suggestion that an interval occupied with proprioception is better than one occupied with nothing, and that the more proprioception the better. Nevertheless, if active movement is occupying the interval it appears impossible to say whether inflow or outflow is most likely to provide the basis for timing.

Although the experiments on the acquisition of accurate estimation of a given time which follow are predominantly concerned with the effects of a visual continuous cue on the learning of this task, some of the features of time estimation suggested in the input and decay models are relevant. If subjects learn to time more accurately when given consistent proprioceptive feedback, then those who use a visual cue to enable them to move at a steady rate will move more consistently, both within and between trials, than subjects who are given terminal feedback and no help in moving consistently. However, if visual feedback is so strong that it distracts subjects' attention from the ongoing proprioceptive cues then visual action information feedback should lead to poor retention when the feedback is removed, just as watching a clock may not help people to time subsequent intervals when a clock is not present.

It is not possible to distinguish between outflow and inflow views of timing in the situation where the subject makes the response actively, however, the predictions from an outflow model are very similar to those from an inflow one in this case, as such a model would have to account for the effect of consistency of movement (if it were found) in terms of consistent output which might then be used to time the movement.

Again, an outflow explanation would account for the effects of continuous visual feedback by suggesting that a movement, the end of which is controlled by feedback, does not have to be completely specified before it occurs, so that subjects who depend on the visual cue have no programme for terminating the response. So from an inflow or an outflow position it could be predicted either that continuous visual feedback (AIF) will give better timing performance than TIF because it makes the rate of movement more consistent, or that it will give poorer performance because subjects make one movement and then wait for the visual information to tell them when to finish the movement, so being both less consistent and less able to time using internal cues. If the latter suggestion were the case it would parallel the results found with the bar pressing task and indicate that the effects of depending on a visual cue present during learning are not confined to only one task.

In the experiments which follow subjects were required to learn to make a given movement in a set time with either TIF or a continuous visual AIF. There is no obvious relationship between the time taken and the visual display of that time so the timed movement cannot be represented directly nor can it be misrepresented by means of gain manipulation as in the bar pressing experiments. 'Inter-sensory' effects can not therefore be expected, but it is expected that those subjects who are trained with AIF will perform differently in practice and test from those trained with TIF although the direction of the difference in test is not clear.

5.2 Experiment 6: Production of 200 msec and 2000msec movements following training with continuous and terminal visual feedback.

Introduction

Method

Subjects

Apparatus

Procedure

Instructions to subjects

Results

A) Mean Absolute Error
   i) All Scores
   ii) Without baseline
   iii) First test trial
   iv) Learning over practice
   v) Summary

B) Mean Constant Error

C) Mean Variable Error

D) Analyses of 2000 msec movements

E) Subjective comments from subjects

F) Strategies

G) Speed of Performance

Discussion

Introduction

In previous experiments subjects given continuous visual feedback (AIF) have tended to move more slowly during practice than those given terminal visual feedback (TIF), and so may have paid more attention to response produced feedback. When a visual cue is present the accuracy during practice is not independent of the time taken to make the movement and it is difficult to disentangle the effect of speed of movement during practice from accuracy in practice when one comes to consider accuracy under test conditions. If, however, the task is one of learning to make a movement of set length in a given time then the accuracy of performance and the time taken are the same, so that differences in performance can be more clearly attributed to the feedback condition.

A continuous visual cue in a time estimation task would move towards a target at a set rate so that the subject could anticipate the correct time for completing the movement. The response of the subject could take two forms - the subject could make a fast initial movement, wait until the visual cue indicates that the time is almost up, and then shoot the slider home, or, s/he could use the continuous visual cue to control the speed of a response, so that it was produced smoothly and in the correct time using continuous movement. The former strategy might be expected with this task on the basis of the bar pressing studies, and would be expected to lead to inferior retention of the time interval as control would be external and could prevent the build up of an internal timing mechanism. Watching a clock may enable accurate timing of an interval but prove of little help on subsequent occasions when a clock is not present. Thus such feedback would be 'action' feedback, or information which promotes good performance but not retention.

Terminal feedback is given after the estimation of time has been made, so the subject is forced to use some internal timing device but may modify the time estimate on subsequent trials. It is expected that AIF subjects will, as with the previous task, be more accurate in practice but less so in test than TIF subjects. If this were so then the effects of AIF would be shown not to be restricted to one experimental situation, and to be more important than the time taken to make a response.

As visual feedback cannot be used to control fast movements, i.e. to allow their alteration during execution, the effects of AIF and TIF should not differ for such a movement. This experiment looks at two movement times - 2000 and 200 msecs - and the effects of AIF and TIF training, and as visual feedback can only be used for movements over this duration it is expected that subjects will be unable to utilise AIF in the fast condition so that only the 2000 msec condition with AIF will show the characteristic accuracy in practice and inaccuracy in test. However, if the continuous visual cue can be used to regulate the consistency of the movement, and thus provide a consistent trace by which a judgement of time can be made, then both AIF conditions might be expected to show greater accuracy in test than the TIF conditions. For the fast condition this implies that velocity of movement can be changed more quickly than direction (Gibbs 1965, Angel and Higgins 1970), so that visual feedback can be used to control some aspects of movements within 200 msecs.

Thus, there are two possible outcomes of this experiment, either the AIF slow condition will give results which are more accurate in practice and inaccurate in test than those from the TIF condition while with the fast movement both types of feedback have the same effects, or both AIF conditions will give more accuracy in test than the TIF conditions because consistency of movement is encouraged.

Method

Subjects

Subjects were 40 undergraduate and post-graduate members of the University of Leicester all of whom took part voluntarily and without payment. There were 20 males and 20 females. Ages ranged from 18 to 27 years with a median of 20 years.

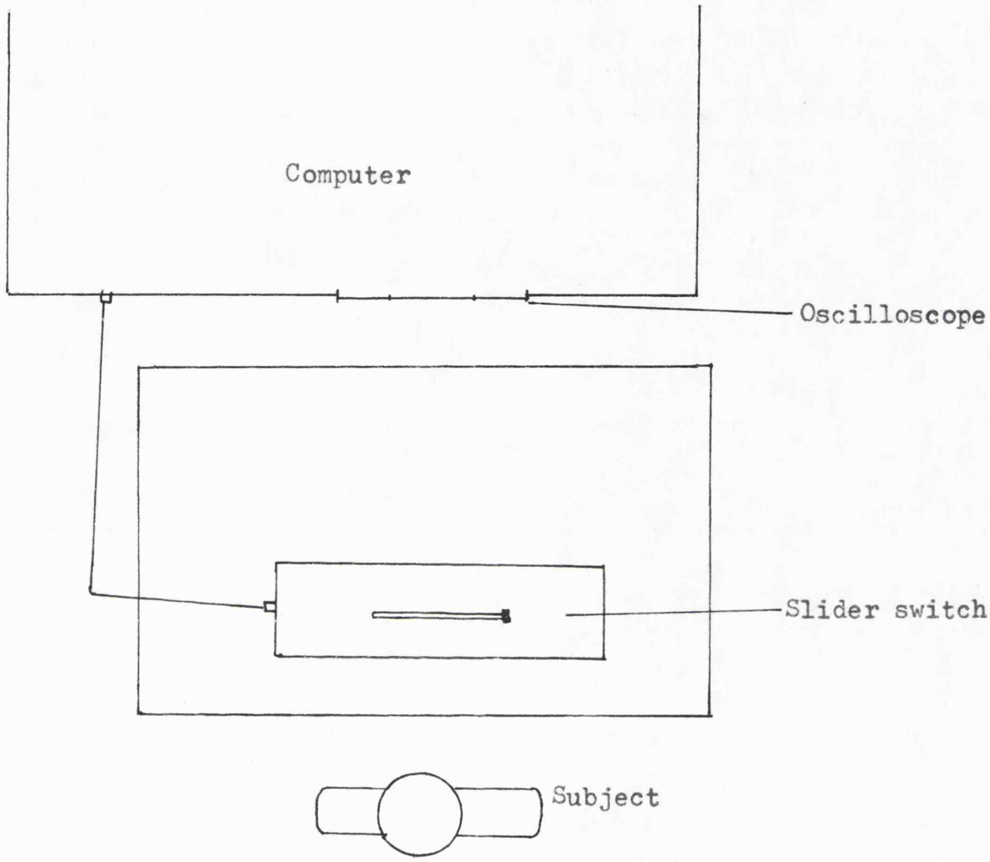
Apparatus

The apparatus consisted of a slider switch 6.5 cms long built into a flat box 38 cms long, 20 cms wide, and raised 4.5 cms from the table top on which it rested. The voltage output from the slider, which increased as the switch was moved along its length, was input to a PDP Lab8E computer, the oscilloscope of which was used for the display.

The slider switch in its box rested on a table directly in front of the oscilloscope. The table top was 70 cms from the floor and the oscilloscope was 130 cms from the floor so that the display was at approximately eye height when the subject was seated at the table. The chair seat was approximately 45 cms from the floor, and the chair was placed directly in front of the oscilloscope, so that the subject was separated from it by the width of the table (85 cms). (See layout diagram Figure 11).

For all conditions the computer was programmed to produce two target marks on the screen, 5cms from the base. These marks were 0.5 cms high and 8.5 cms apart. The mark to the left of the

Figure 11. Apparatus layout for time learning task.



screen was the start for the visual feedback while that to the left was the target. The slider switch was moved from left to right, so that the directions of the movement and the display were congruent.

When the slider was moved from left to right in the AIF practice conditions a line of dots appeared on the screen. In the 2000 msec condition this line grew from the mark on the left of the screen at a rate of 4·25 cms per sec, while for the 200 msec condition the rate was 42·5 cms per sec. This line reached the target mark when the required time had elapsed, and was stopped by the slider reaching the end of its track, whenever that occurred. The visual feedback remained visible for 1.5 seconds after the end of the movement.

The 200 msec condition allowed for very few dots to be displayed on the screen (approx 1 per cm). The computer was unable to cycle fast enough to plot more dots in such a short time. However, in the second during which the feedback remained on the screen after the movement was completed the number of dots was increased to that in the TIF condition (approximately 6 per cm). This accentuates the similarity between the terminal and active feedback conditions at this speed, but was necessary in order that resolution should be the same for both conditions.

For the terminal feedback conditions the subject moved the slider with only the two target marks on the screen. When the movement was completed a line appeared on the screen immediately and remained in view for 1.5 seconds. This line had approximately 6 dots per centimetre, and its length indicated the time taken for the previous movement.

Procedure

Subjects were randomly assigned to one of four groups with equal numbers of males and females in each condition. Two groups received AIF during practice, one making movements of 2000 msecs and the other making movements of 200 msecs, these will be known as AIF.S (AIF, slow movement) and AIF.F (AIF, fast movement), respectively. The other two groups received TIF training for the two movement speeds and will be known as TIF.S and TIF.F.

Five pre-test or baseline trials were given to all subjects in which they received no feedback of any kind. Ss moved the slider in what they estimated to be the correct time in response to the appearance of the target marks. When the movement was completed the target marks disappeared and the slider was returned to the start by S. After 5 seconds the marks reappeared and S made another estimation. Subjects were not required to respond immediately to these marks but used them as a cue that another response could be made.

There were 30 practice trials in all conditions. In the AIF group continuous feedback was given in the form of the line already described, when the response finished the line was removed, to be replaced immediately by a line similar to that produced as TIF, this remained visible for 1.5 seconds. In the TIF condition subjects moved the slider with only the target marks on the screen. When the movement was finished a line appeared on the screen immediately and remained in view for 1.5 seconds. For both conditions the display then disappeared completely and the target marks reappeared after 3.5 seconds. After the 30th practice trial the teletype produced an auditory cue and initiated the test trial. Subjects were also reminded by E that they were to try to reproduce the correct movement time without feedback. The test trials were of the same type as the pretest trials.

After test there was an interval of 3 minutes before retest during which subjects were questioned as to how they had tried to learn the task and how they felt when the feedback was removed. Five retest trials without feedback followed.

Instructions to subjects

These were as follows:

AIF 200 msecs. (AIF.F)

"Your task in this experiment is to learn to move this slider from this end to the other (pointing) in 200 milliseconds, that is, a fifth of a second. First I would like you to move it in what you estimate to be a fifth of a second. When the switch reaches the end of the track the two marks on the screen will disappear, return the slider to the starting position and wait for them to re-appear, then repeat the movement. Always wait for the two marks on the screen before moving the switch".

After five estimates had been made the teletype produced a nonsense message which acted as an auditory cue for further instructions.

"Now you are going to learn to make the movement in 200 msecs*. As you move the slider a line will grow across the screen from the mark on the left. This line represents time and it stops when you reach the end of the track. If you can stop the line at the second mark on the screen you will have made the movement in 200 msecs. When you have finished the movement the line will disappear for a moment and then return to show how long you took for that trial. If it does not reach the second mark your movement was too fast, if longer then the movement was too slow.** Return the slider to the starting position and wait for the cue marks before trying again.

When you have practised like this for some time the teletype will make the noise you've just heard and the line will no longer appear, you must then try to reproduce the movement in the time which you have been learning. Remember you are to learn to make the movement in one fifth of a second so that you reproduce it by yourself".

When the teletype indicated that practice was ended E said

"The line will no longer appear . Try to reproduce the correct time".

Three minutes after the end of the test S was told

"The last few trials will now be repeated, the line will not appear. Try to reproduce the movement in one fifth of a second remembering what you have been learning".

TIF 200 msec (TIF.F)

Instructions were as for AIF except for those between * and **. These were altered as follows:

"When you have completed the movement a line will appear on the screen telling you how long you have taken. The line will begin at the mark on the left and represents time. If it reaches to the second mark you have made the movement in the correct time, if the line is longer you have taken too long i.e. been too slow, if it does not reach it you have not taken long enough, i.e. you have moved too quickly".

AIF 2000 msecs (AIF.S)

Instructions as for AIF 200 msecs except that all references to the time interval were changed to "two seconds".

TIF 2000 msecs (TIF.S)

Instructions as for TIF 200 msecs except that all references to the time interval were changed to "two seconds".

Results

Error on each trial was calculated as a percentage of the target time and these percentages were averaged to give four mean error scores per subject, one for each of the four stages (baseline, practice, test and retest). Three error measures were used: absolute mean percentage error (AE), constant mean percentage error (CE) and the standard deviation of the latter (VE).

As it was felt that AIF and TIF subjects might learn the task differently, (e.g. AIF Ss could move the slider almost to the end of the track, wait for the time to elapse and shoot the slider home, while TIF Ss should move much more smoothly), the computer sampled the position of the slider at regular intervals (200 msecs) during each trial. This enables an overall speed of movement curve to be calculated for each subject for each section of the experiment. Due to the very short target time involved in the 200 msec condition it was not possible to measure changes in the velocity of movement, but it is unlikely that any large, controlled change of speed would be seen within such a short movement without much more sophisticated measurement techniques.

A) Absolute Error

i) All scores

The mean AE scores for two types of feedback, two movement times and four stages of learning are presented in Figure 12, and standard deviations of these means in Table 41. Results have been graphed rather than tabled in order to provide easy comparisons with the

Figure 12: **Mean Abs. % Error for two feedback conditions and two speeds of movement.**

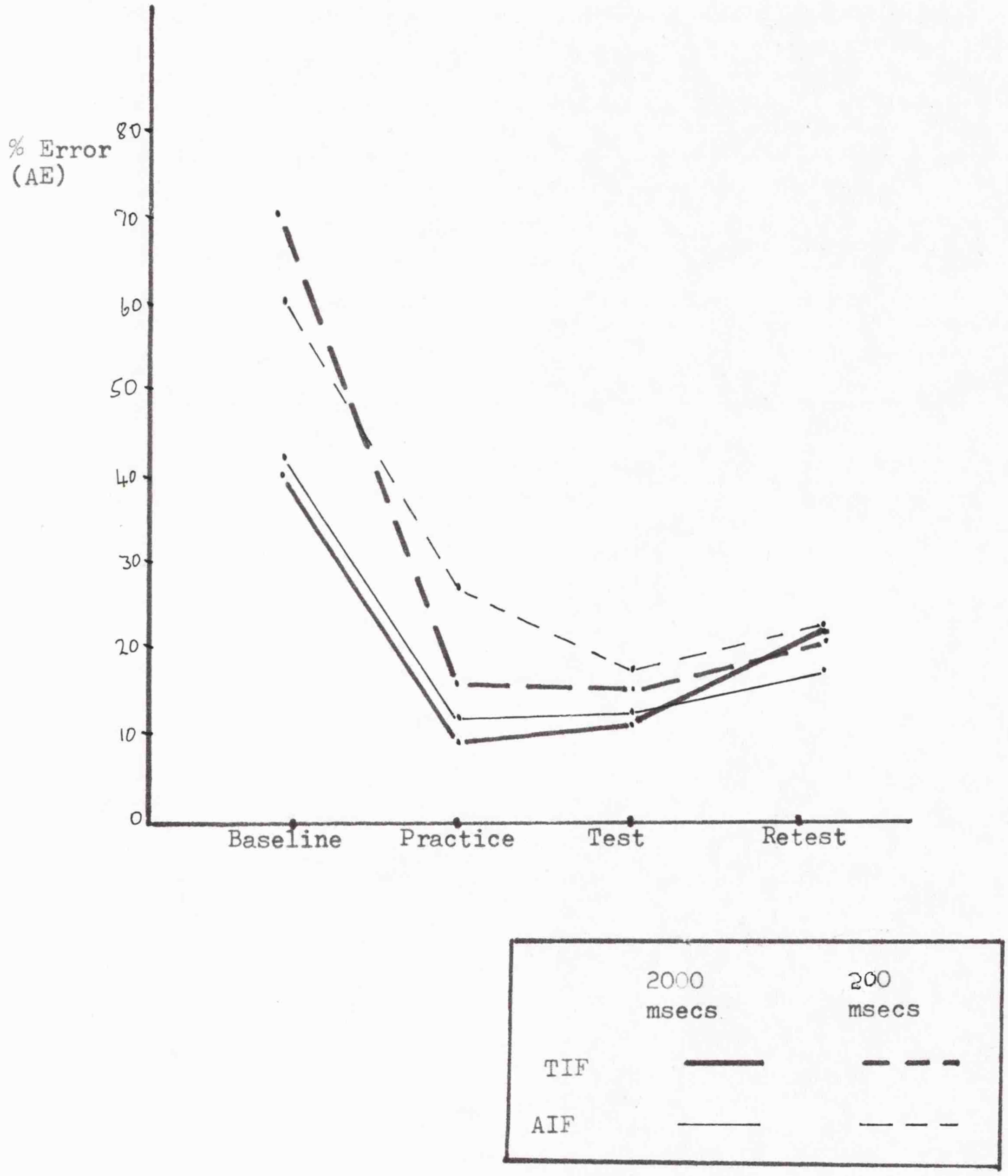


Table 41 Standard deviations and ranges for means in Figure 12.

		Baseline	Practice	Test	Re-test
AIF.F	S.D.	26.07	9.18	8.20	10.99
	Range	24.8- 119.50	16.29- 43.97	7.3- 33.60	10.0- 42.80
AIF.S	S.D.	22.42	4.39	8.13	13.03
	Range	8.44- 88.30	3.43- 21.00	4.79- 31.34	7.13- 45.36
TIF.F	S.D.	29.74	3.19	4.54	11.33
	Range	22.2- 144.4	12.52- 23.81	9.00- 26.40	7.40- 49.70
TIF.S	S.D.	20.94	5.65	8.19	11.14
	Range	10.53- 72.44	5.43- 22.02	2.51- 31.30	8.23- 46.11

other measures. The AE means were analysed by a 2 x 2 x 4 ANOVA with repeated measures on the last factor and the analysis is shown in Table 42. The movement times differed, as did the stages of learning, but there was no difference between AIF and TIF performance. There was an interaction between movement time and stage of learning, which indicates that subjects in the fast movement conditions make larger initial errors than those in the slow conditions but this difference decreases over successive stages and is no longer apparent in retest.

The stage of learning difference was investigated using an a posteriori test (Tukey 1957) which indicated that the baseline was significantly worse than all other conditions ($p < 0.01$), but the other stages did not differ from each other. This means that learning occurred in all conditions.

ii) Without baseline

As it was felt that the large differences between pretest and other scores might obscure other effects over practice, test and retest, a 2 x 2 x 3 ANOVA was carried out on the same data without the baseline scores. Again movement times differed significantly as did the stages of learning (Table 43). Retest errors are generally larger than test and practice errors. No differences were found between types of feedback.

iii) First test trial

Although no differences were found between test scores for the four conditions a 2 x 2 ANOVA on the first test trials for each group showed a significant interaction between speed of movement and type of feedback (means and analysis: Table 44). This is due to the extremely high error scores recorded in the first test

Table 42 — Analysis of the absolute error means presented in Figure 12.

Source	DF	SS	MS	F	P
Between					
1) Type of training	1	50.72	50.72	0.11	NS
2) Movement time	1	3800.75	3800.75	8.53	**
1 x 2	1	0.19	0.19	0.00	NS
Subjects within groups	36	16031.88	445.33		
Within					
3) Stage of training	3	37924.44	12641.48	36.74	**
1 x 3	3	259.02	86.34	0.25	NS
2 x 3	3	3063.51	1021.17	2.97	*
1 x 2 x 3	3	823.23	274.41	0.80	NS
3 x Ss x groups	108	37163.88	344.11		
Total	159	99117.62			

Table 43 — Analysis of absolute error means; practice, test and retest

Source	DF	SS	MS	F	P
Between					
1) Type of training	1	181.72	181.72	1.72	NS
2) Movement time	1	771.60	771.60	7.29	**
1 x 2	1	147.70	147.70	1.40	NS
Ss within groups	36	3810.21	105.84		
Within					
3) Stage of learning	2	695.83	347.92	4.74	*
1 x 3	2	45.09	22.54	0.31	NS
2 x 3	2	439.42	219.71	2.99	NS
1 x 2 x 3	2	268.60	134.30	1.83	NS
3 x Ss x groups	72	5287.85	73.44		
Total	118	11648.02			

Table 44 — Error on first test trial, all conditions: means and analysis.

	AIF		TIF	
	200 msec	2000 msec	200 msec	2000 msec
Mean (AE)	26.65	12.35	13.50	14.99
S.D.	14.55	8.69	6.82	12.62
Range	0.50- 48.00	4.10- 30.45	2.50- 19.50	0.85- 37.35

Analysis:

Source	DF	SS	MS	F	P
1) Movement time	1	409.92	409.92	2.99	NS
2) Type of training	1	276.41	276.41	2.02	NS
1 x 2	1	622.92	622.92	4.55	*
Within cell	36	4929.62	136.93		
Total	39	6238.86			

trial in the AIF.F condition. Subjects required to learn a very fast movement with AIF were very confused when the feedback was removed and some did not understand what was expected of them.

iv) Learning over practice

When AIF was present on a bar pressing task, subjects performed accurately throughout practice. In this experiment however, there appears to be little difference in the absolute error scores produced during practice with the two types of feedback. To investigate this and to show that learning was occurring over practice an analysis was performed on the mean baseline error scores, the mean error scores for the first 10 practice trials, and those for the last 10 trials. These means and the analysis are presented in Table 45.

Movement time was again a significant factor, as was the stage of performance. Errors decrease over these three stages so that baseline is less accurate than the first 10 practice trials which are in turn more accurate than the last 10 trials. No difference between the types of feedback was found. AIF subjects do not appear to use the visual cue to control the accuracy of performance in practice.

The very fast movement condition does not allow subjects to use AIF to guide the end of their movements, but two seconds should allow subjects to use the visual feedback as a performance cue. That they did not do so can be clearly seen from the error curves over practice in this condition which are plotted in Figure 13. AIF subjects behave more like TIF subjects in this task, they do not appear to use the feedback as a performance cue.

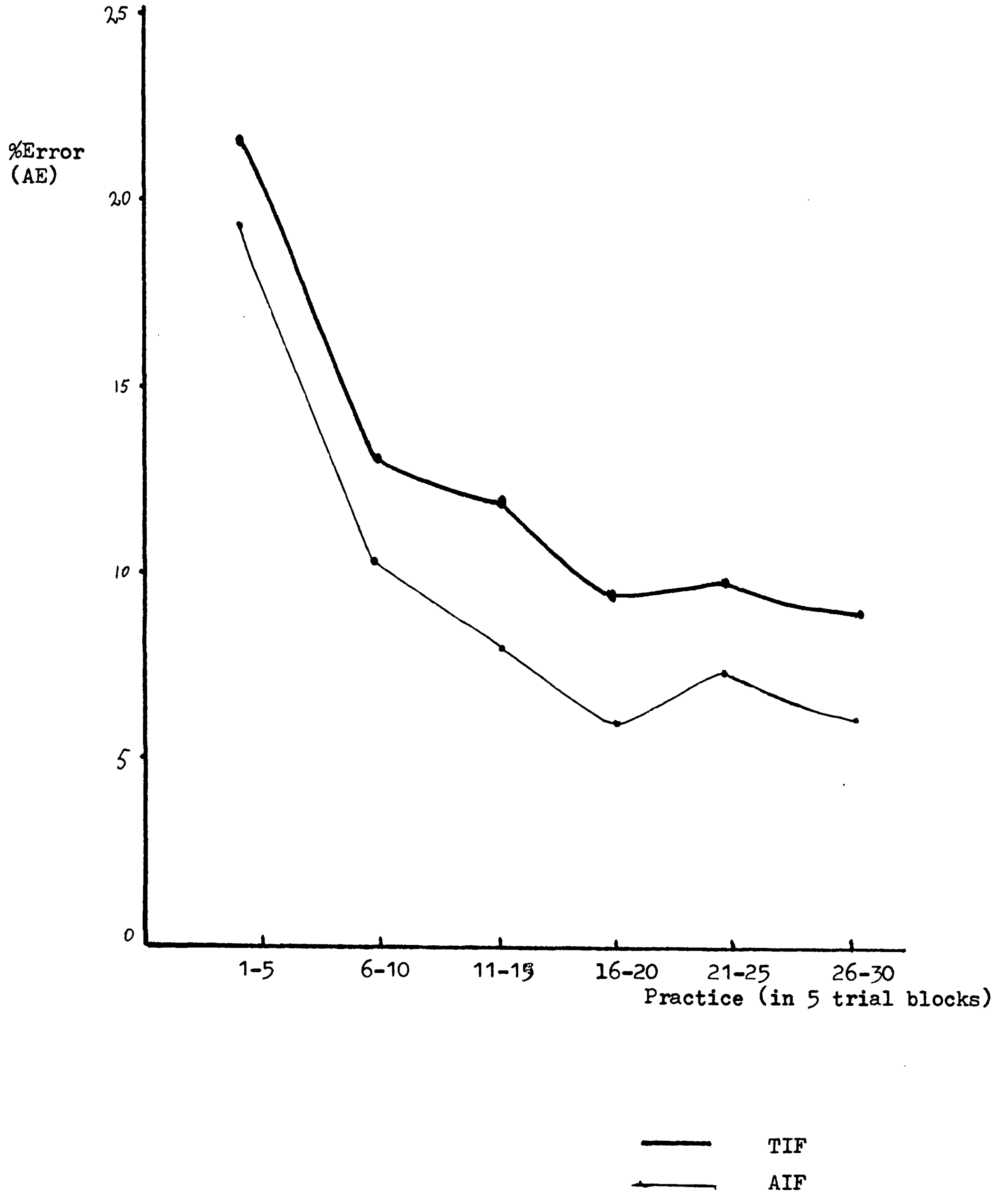
Table 45 Improvement over practice: mean absolute error scores for baseline, first 10 practice trials, and last 10 practice trials: and analysis of these means.

		Baseline	First 10 practice	Last 10 practice
AIF	200 msec	60.09	23.51	13.35
	2000 msec	42.69	15.01	6.47
TIF	200 msec	69.35	36.28	20.10
	2000 msec	39.19	16.65	9.62

Analysis

Source	DF	SS	MS	F	P
Between					
1) Movement time	1	7210.24	7210.24	11.95	**
2) Type of training	1	66.94	66.94	0.11	NS
1 x 2	1	111.32	111.32	0.18	NS
Ss within groups	36	21729.54	603.60		
Within					
3) Stage of learning	2	35254.89	17627.44	45.16	***
1 x 3	2	1171.76	585.88	1.50	NS
2 x 3	2	357.77	178.89	0.46	NS
1 x 2 x 2	2	1060.54	530.27	1.36	NS
3 x Ss x groups	72	28105.46	390.35		
Total	119	95068.46			

Figure 13. Means of practice error in S-trial blocks for a 2000 msec movement time



v) AE: Summary

The absolute error scores in this experiment show a very different pattern from those in the bar pressing studies. The type of feedback given in practice does not have differential effects on overall accuracy in test or retest. More surprisingly, although Figure 13 shows that over practice AIF errors are consistently smaller than TIF errors, this is not a significant difference when calculated over the first and last 10 practice trials. Subjects' reports that they did not use the AIF as a performance cue, and the results of analysis of their speed and acceleration (which will be considered later), also indicate that the learning situation with AIF is not the same as in previous experiments.

B). Constant Error

Mean constant error scores indicate direction of error over the stages of learning the task, and as can be seen from Figure 14 they are very different from AE scores. Further information about the variation of the means can be found in Table 46, and the results of a 2 x 2 x 4 ANOVA in Table 47. Stage of learning was the only significant factor, and a Tukey test showed that the baseline was different from all other stages. Subjects tended to underestimate the required times in the baseline condition and to overestimate more after practice.

It can be seen from Figure 14 that the AIF.S condition is different from the others, in that subjects have a tendency to underestimate the target time throughout. As the slow movement condition is most comparable with the bar pressing task in that it could allow visual feedback to influence performance this will be analysed separately (see section D below).

Figure 14. Mean constant error scores for two types of feedback and two speeds of movement.

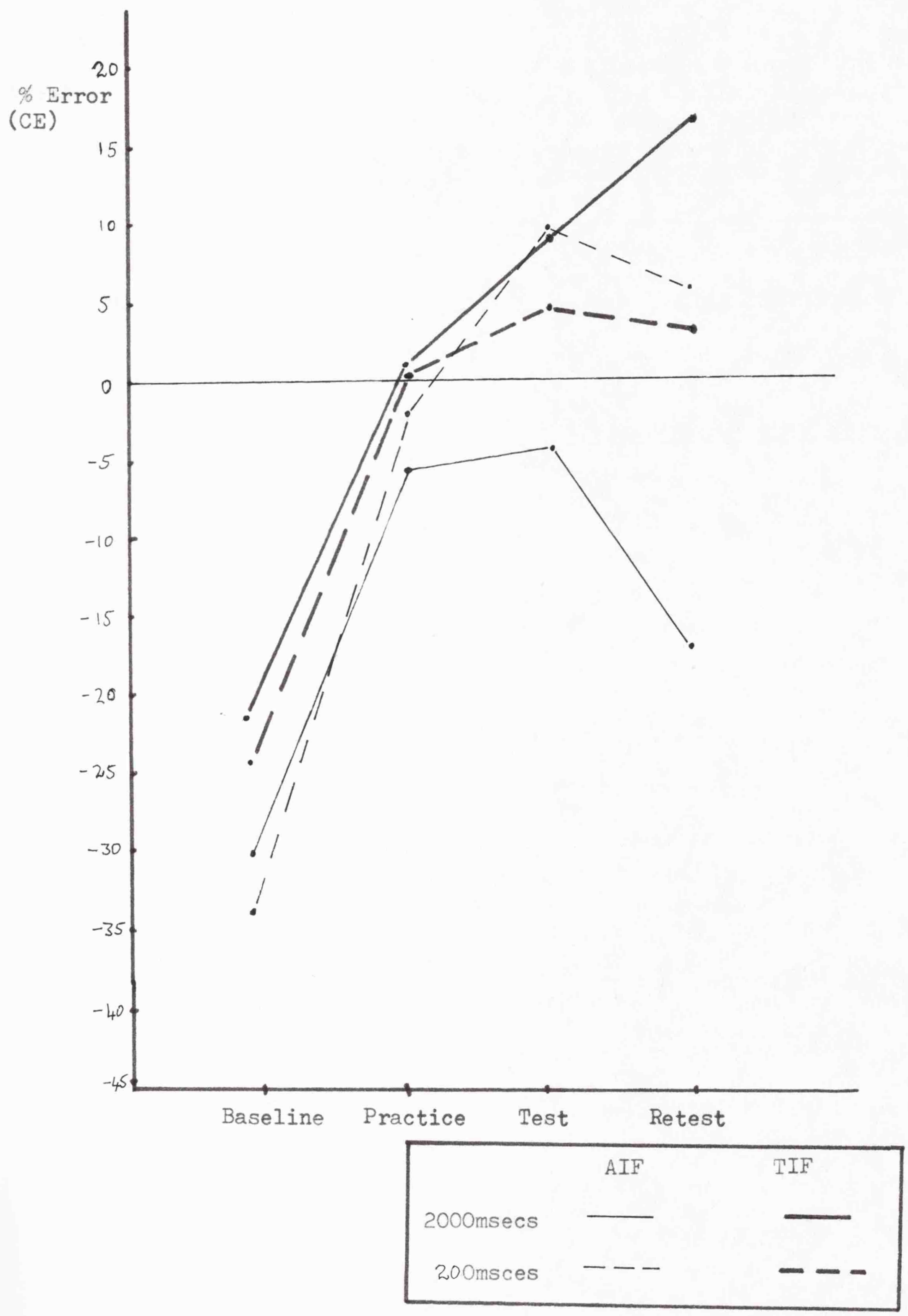


Table 46 — Standard deviations and ranges of the constant error means in Figure 14.

		Baseline	Practice	Test	Retest
TIF.F	S.D.	64.44	4.89	8.72	15.03
	Range	-65.8- 144.40	-5.72- 11.58	-8.50- 20.20	-10- 49.7
AIF.F	S.D.	55.24	17.09	13.48	21.73
	Range	-75.3- 117.30	-22.87- 28.75	-16.80- 33.60	-23.20- 42.80
TIF.S	S.D.	30.50	4.89	13.00	18.71
	Range	-72.44- 31.87	-7.75- 7.78	-14.74- 31.30	-16.04- 46.11
AIF.S	S.D.	35.90	5.36	12.80	17.93
	Range	-68.40- 48.19	-19.45- 1.67	-31.34- 14.62	-47.36- 8.36

Table 47. Analysis of the CE means in Figure 14

Source	DF	SS	MS	F	P
Between					
1) Speed of movement	1	894.09	894.09	1.25	NS
2) Type of feedback	1	1797.85	1797.85	2.50	NS
1 x 2	1	872.19	872.19	1.21	NS
Ss within groups	36	25844.63	717.91		
Within					
3) Stage of learning	3	36693.06	12231.02	21.94	***
1 x 3	3	3585.90	1195.30	2.14	NS
2 x 3	3	1505.39	501.80	0.90	NS
1 x 2 x 3	3	220.22	73.41	0.13	NS
3 x Ss x groups	108	60196.51	557.38		

C) Variable Error

Subjects' variation around their algebraic means indicates to some degree the clarity of the model which is being reproduced. Variable error is graphed in Figure 15, and further information is presented in Table 48. The results of a 2 x 2 x 4 ANOVA (Table 49) show that speeds of movement and stages of practice differ, but there is no difference in the consistency of responding with AIF or TIF present during training. On the basis of the bar pressing experiments it might be expected that practice variation would be less for AIF trained subjects than for TIF trained ones. The lack of a significant difference is affected by the extreme variability of AIF.F practice responses and analysis of two second movements alone may produce results more like those in previous experiments.

It is suggested that those subjects learning the shorter movement time found it difficult to learn and that the continuous feedback condition was particularly confusing, so that subjects were unable to produce consistent movements. Either the instructions to use very fast continuous feedback or the effort of doing so interfered with performance during practice. It may be that subjects cannot use the feedback but allow its presence to upset them by adding to the strangeness of the task.

D. Analyses of 2000 msec. results.

If the very fast condition and continuous feedback unite to confuse subjects then only the slow movement in this experiment can be used to investigate the role of continuous feedback in a task of this kind, and further analyses of absolute, constant and variable error were carried out on the two slow conditions only.

Figure 15. Variable error scores for all conditions over 4 types of learning

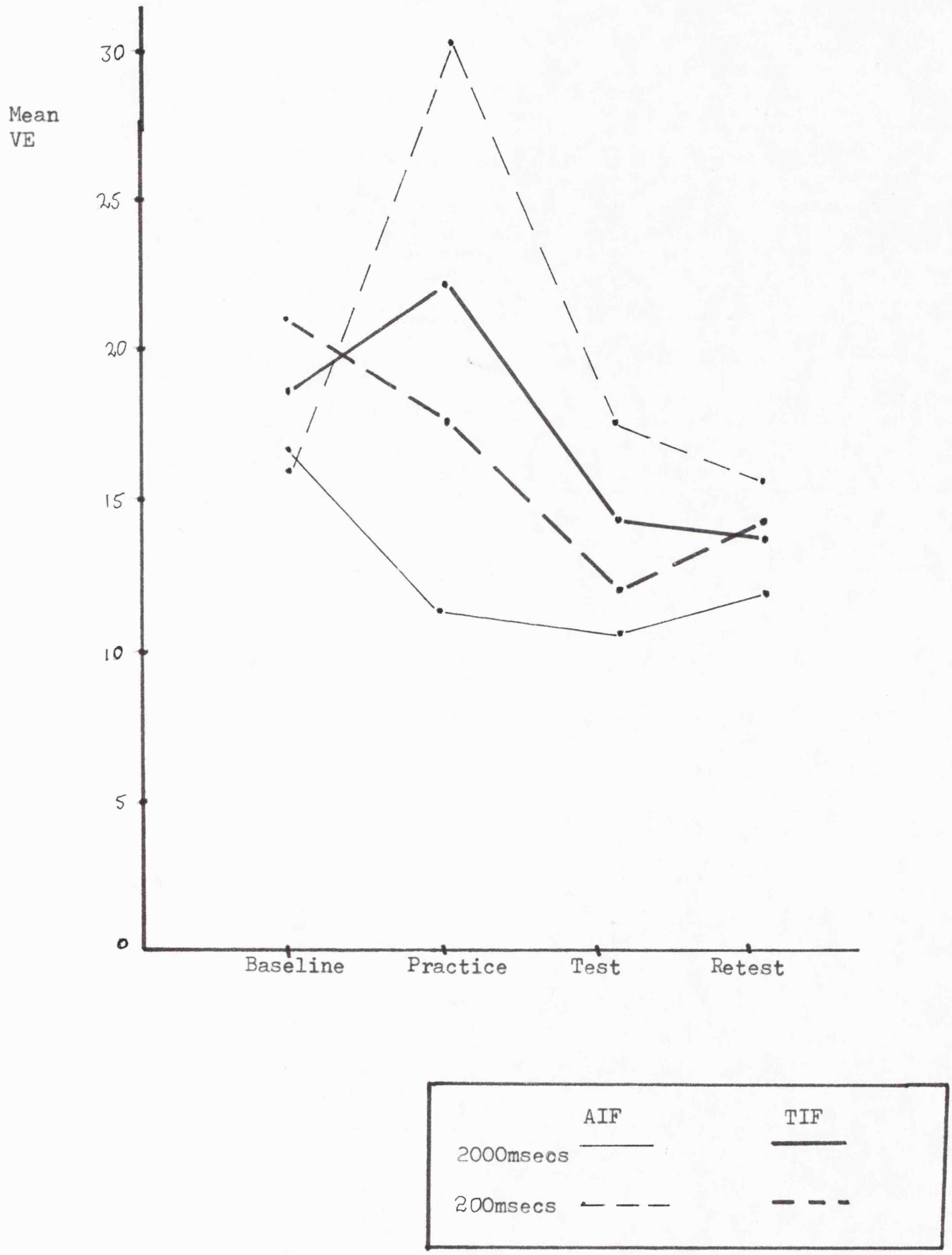


Table 48 Standard deviations and ranges of the VE means in Figure 15

		Baseline	Practice	Test	Retest
TIF.F	S.D.	15.12	7.80	4.71	6.08
	Range	3.36 50.79	11.96- 42.89	5.59- 21.49	5.18- 25.41
AIF.F	S.D.	18.33	9.52	6.52	7.21
	Range	5.18- 70.01	19.60- 50.05	8.32- 29.89	8.27- 32.89
TIF.S	S.D.	18.38	7.78	5.59	6.75
	Range	5.95 70.03	6.70- 34.51	2.94- 22.49	4.32- 27.76
AIF.S	S.D.	9.62	4.12	4.60	4.72
	Range	5.14- 33.42	3.29- 17.39	4.56- 18.67	4.88- 21.47

Table 49 — Analysis of the variable error means in Figure 15.

Source	DF	SS	MS	F	P
Between					
1) Speed of movement	1	1030.28	1030.28	6.37	*
2) Type of training	1	39.35	39.35	0.24	NS
1 x 2	1	248.03	248.03	1.53	NS
Ss within groups	36	5826.98	161.86		
Within					
3) Stage of learning	3	1767.38	589.13	4.25	**
1 x 3	3	675.51	225.17	1.62	NS
2 x 3	3	343.50	114.50	0.83	NS
1 x 2 x 3	3	371.67	123.89	0.89	NS
3 x Ss x groups	108	14980.00	138.70		

A 2 x 4 ANOVA on absolute error scores indicated only that the stages of learning differed (see Table 50) but a similar analysis of constant error scores (Table 51) indicated that both factors gave significant differences in performance. The two types of feedback seem to give quite different results in the slow movement, and Figure 14 indicates that AIF trained subjects underestimate the target time throughout all trials. As this difference is apparent in the baseline condition, in which the two conditions should perform equally, an analysis of covariance was performed on practice, test and retest scores, with baseline as the covariate. The results of this analysis (Table 52) confirm the finding that the direction of error produced by subjects in the two feedback conditions differs significantly. AIF subjects underestimate more than TIF subjects.

A further analysis of the variable error scores for the slow movement (Table 53) showed that AIF and TIF groups did not differ in the consistency with which they performed the task. In general, when the visual cue can be used to control movement AIF subjects do not differ from TIF subjects in accuracy or in consistency but they do differ in the direction of errors made, although there is quite a large range of error in both cases.

E) Subjective Comments from Subjects

The subjective comments of subjects after testing related in general to the method they used to learn the task, accuracy when the feedback stopped, and perception of the task as being different when the feedback stopped. Subjects did not all comment on the same areas and the discussion was very informal.

Table 50 — Analysis of AE means for the 2000 msec conditions

Source	DF	SS	MS	F	P
Between					
1) Type of feedback	1	22.34	22.34	0.06	NS
Ss within groups	18	6258.61	347.70		
Within					
2) Stage of learning	3	10931.74	3643.91	24.80	**
1 x 2	3	194.81	64.94	0.44	NS
2 x Ss x groups	54	7933.82	146.92		

Table 51 — Analysis of CE means for the 2000 msec conditions

Source	DF	SS	MS	F	P
Between					
1) Type of feedback	1	2587.24	2587.24	5.19	*
Ss within groups	18	8977.22	498.73		
Within					
2) Stage of learning	3	9849.10	3283.03	7.64	**
1 x 2	3	1111.03	370.34	0.86	NS
2 x Ss x groups	54	23213.69	429.88		

Table 52 — Results of a covariance analysis of the CE means for the 2000 msec condition, with baseline as the covariate.

Source	DF	SS	MS	F	P
Between					
1) Type of feedback	1	1924.63	1924.63	7.05	*
Ss within groups	18	4911.83	272.88		
Within					
2) Stage of learning	2	597.05	298.52	1.90	NS
1 x 2	2	645.27	322.64	2.05	NS
2 x Ss x groups	36	5660.07	157.22		
Adjusted means					
1) Type of feedback	1	1887.62	1887.62	6.55	*
Ss within groups	17	4902.65	288.39		

Table 53 Analysis of VE means for the 2000 msec conditions

Source	DF	SS	MS	F	P
Between					
1) Type of feedback	1	242.70	242.70	2.09	NS
Ss within groups	18	2085.39	115.86		
Within					
2) Stage of learning	3	732.59	244.20	3.14	*
1 x 2	3	54.75	54.75	0.23	NS
2 x Ss x groups	54	4195.68	77.70		

In the TIF.S condition 3 subjects reported that the task was no different when the feedback stopped, 3 that it was easier or that they could concentrate better and 2 that it felt strange or that they were less confident. Seven subjects felt that they were accurate or fairly accurate in the first test.

In the AIF.S condition 5 subjects reported a fair degree of accuracy and 5 that they had been inaccurate (although 2 of these felt their first test trial had been good). None of the subjects in this condition mentioned that they felt different about the task itself when the feedback stopped. This is very different from the AIF subjects in the bar pressing task who tended to feel that the actual characteristics of the bar had changed.

Subjects in the fast conditions were generally unsure of their accuracy although 4 in the AIF and 5 in the TIF condition thought they were fairly accurate in test. No differences in the task were found when the feedback was removed. Subjects in the fast conditions however, did not tend to report strategies of learning apart from comments such as "I tried to get it right". The ballistic nature of this task means that the ongoing alterations cannot be made during a trial and subjects may not be aware of how they tried to learn apart from blindly trying to alter their next production in the correct direction.

F) Strategies

Strategies for learning the task fall into two main categories for the TIF.S group. These are counting (including rhythm or music), and feel of movement (reported as feeling the speed or rate of arm movement or just "How it felt"). The AIF.S group used these plus a third strategy - watching the dots on the screen and simply 'following' them. Some subjects reported only one of these methods and some more than one so that it was difficult to categorise strategies under discrete headings, especially in the AIF group. The frequencies of usage of each category is shown in Table 54.

Table 54 Uses of strategies by AIF.S and TIF.S subjects

Strategy:	Counting	Feel	C+F	Dots	C+D	F+D	C+F+D
TIF.S	5	4	1	-	-	-	-
AIF.S	1	4	-	2	1	1	1

As six subjects in the TIF condition and 3 in the AIF condition report using counting to some extent it appears that verbal mediation is of considerable importance in this task. However, when absolute error results in the TIF condition were split into those who attempted to learn the speed of movement and those who did not (i.e. used counting only) a 2 x 2 ANOVA with 5 subjects per strategy showed no differences between these two strategies for practice and test (Table 55).

Subjects in the previous experiments attended to the visual feedback and used it to keep performance in practice at a high level and it was felt that subjects who reported that they just 'watched the dots' in this experiment might also show good practice performance, perhaps related to poor test performance. This was tested for absolute error scores using a 2 x 2 ANOVA on practice/test and dots/not dots, with 5 subjects in each group. The test error means and the results of the analysis are shown in Table 56.

Table 55a — Mean absolute error scores in practice and test for two strategies in the TIF.S condition.

Strategy:		Practice	Test
Counting	Mean	10.17	10.55
	S.D.	4.55	6.77
	Range	5.43-17.12	2.51-21.01
'Feel' of movement	Mean	14.82	18.29
	S.D.	5.68	7.64
	Range	7.98-22.02	9.10-31.30

Table 55b — Analysis of the means in Table 55a

Source	DF	SS	MS	F	P
Between					
Strategy	1	191.93	191.93	2.52	NS
Ss within groups	8	610.57	76.32		
Within					
Practice/test	1	18.61	18.61	0.85	NS
1 x 2	1	11.74	11.74	0.54	NS
2 x Ss x groups	8	175.21	21.90		

Table 56a — Mean absolute error scores in practice and test for two types of strategy in the AIF.S condition.

Strategy:		Practice	Test
'Dots'	Mean	6.86	19.25
	S.D.	1.99	7.32
	Range	3.43- 9.11	9.29- 31.34
'Not Dots'	Mean	12.13	7.81
	S.D.	4.55	3.63
	Range	8.15- 20.99	4.79- 14.62

Table 56b — Analysis of means in Table 56a.

Source	DF	SS	MS	F	P
Between					
1) Strategy	1	47.62	47.62	1.45	NS
Ss within groups	8	262.31	32.79		
Within					
2) Practice/test	1	81.53	81.53	3.35	NS
1 x 2	1	348.78	348.78	14.32	**
2 x Ss x groups	8	194.78	24.35		

Differences between strategies were not significant nor were those between practice and test but the interaction was significant. This indicates that those subjects who used the line to guide their responses were actually more accurate in practice and less so in test than those who did not. This finding is obviously suggestive rather than conclusive but for this task strategies for learning may be of great importance to the way the feedback is used.

A comparison between the 4 TIF subjects who used speed of movement and the 4 AIF subjects who also did so was carried out using Mann Whitney 'U' tests on practice and test scores (AE). For practice there was no difference between the two types of feedback ($U = 5$) but for test every AIF score was lower than the lowest TIF score, i.e. $U = 0$ ($p = 0.014$). This is also merely a suggestive finding but it may be that AIF is of use in timed movement learning in that it can help form a speed of movement for those subjects who had a 'feel' or 'speed' of learning strategy, and this may provide consistent kinaesthetic feedback and so aid timing.

G) Speed of performance with two types of feedback

The speed at which subjects carried out the task was investigated using the timed distance samples taken during each trial. The position of the slider at these sampled times could be calculated and plotted against time to show speed of movement. Average curves for the first fifteen practice trials and the last fifteen practice trials were obtained. The point at which each curve reached either the time or the distance limit for the task was calculated and from this a straight line was plotted to the origin, representing the curve which would have been found had the subject moved at a constant speed. Equidistant points on this line (as many as were sampled in the subject's performance before one of the limits was reached) were each subtracted from the actual average points produced by the subject and these differences were squared and then summed. This sum of squares value was used as an estimate of how close the subject came to moving the slider at a steady speed.

If the AIF subjects watched the feedback to such an extent that they moved quickly initially, waited, and then ended very quickly as the feedback line neared the target, they should have larger SS scores than the TIF group who cannot wait in this way. The sum of squares per subject over the first 15 AIF and TIF trials were compared using a 't' test, as were the last 15 practice trials. Neither test was significant (see Table 57).

Table 57 — Mean sums of squares scores for speed of movement in two practice blocks

Practice trials	TIF	AIF	t
1st 15	0.016	0.0106	0.859 N.S.
2nd 15	0.0099	0.0096	0.722 N.S.

There was no correlation found between AIF practice style and test scores (AE). Spearman r_s for total SS and practice error was -0.09 and for total SS and test error it was 0.18.

Again it must be concluded that there was no difference in the way in which subjects performed the task with two conditions of feedback. Subjects in both groups moved equally smoothly and the second 15 trials were smoother than the first 15 trials.

Discussion

The results of this experiment were different from those found in previous experiments with AIF. There was no difference in accuracy between AIF and TIF in practice, in which the former was expected to give more accurate results, nor in test, in which the latter should have been more accurate had results similar to those with a bar pressing task been found. This does not mean that AIF training only causes test error in such bar pressing tasks, as one of the striking results with time learning is that subjects do not appear to use the continuous visual cue as would be expected. They do not allow the external information about time to control their movements and thus are much less likely to become dependent on such a cue.

When subjects are trained with AIF they typically perform well in practice, making very few errors but guiding the movement visually over the last section so that no errors are made. In this time-estimating task such accuracy is not apparent. One reason for this may be that subjects have to learn the length of the track along which the slider moves, as well as learn the time of the movement, while TIF subjects receive one overall piece of information when they have finished the movement. It is unlikely that this explanation can account for the large initial errors in timing made in practice by those given AIF training, although some subjects may have underestimated the length of the track and so produced errors of under estimation of time in the 2000 msec. condition. As the difference in direction of error in this condition was the only one found between AIF and TIF groups it cannot be assumed that dependence on the visual cue alone caused under-estimation by AIF subjects.

Subjects did not learn to move part of the distance and then finish very quickly when the cue approached the target, if they had done so the problem of the length of the track would not arise. However, subjects used a large variety of strategies and combinations of strategies in both conditions and it is likely that these strategies, especially counting or singing, have contributed to the finding that both types of feedback give quite accurate test results.

The very fast condition did not show any advantage of the AIF treatment, indeed it became apparent that subjects did not understand what they were to do, or what the visual display was for, as they continued to make large errors in practice. As the interval used is a very short one subjects are very unused to the relevant range of times and it may be that they cannot become any more accurate, at least in the number of practice trials given here.

Subjects' reports of the task after the visual cue was removed support the suggestion that this task is not the same as the bar pressing one. There were no reports of impressions of change in the characteristics of the apparatus, which may mean that there was no mis-match between visual and proprioceptive feedback in this task. Subjects did not often report any feelings that they were 'lost' without the cue, and as many AIF as TIF subjects felt quite confident of their accuracy. This would suggest that the visual cue is not dominating the response and controlling the feedback expectancies from future responses.

The lack of dependence on the visual cue may indicate that for a timing task kinaesthetic or proprioceptive cues are normally used and are not distorted or weakened by concurrent visual input. However, it is not as simple as this, mainly because of the strategies which the subjects report using. There is a suggestion in the data that subjects trained with AIF who use the visual cue in the expected way, i.e. are very accurate in practice because they allow the dots to control their movement, are indeed more accurate in practice and less so in test than those who use a central strategy such as counting. In addition, when those who report a 'feel' of the task strategy in AIF and TIF conditions are compared the AIF trained subjects perform more accurately in test. This appears to support the suggestion that a continuous visual cue is more useful when subjects are using proprioceptive feedback, perhaps because it leads to more consistent practice.

The question of subject strategies is one which must be investigated further, although it is not always easy to fit a subjective account into any strategy category. However, the problem of counting and other rhythmic strategies is that with these it is impossible to assign importance to either visual or kinaesthetic feedback as these can only assume importance when a verbal cue is not operating. It does not make sense to consider the role of feedback in verbally controlled time estimation, except that it is used to make the counting more accurate.

For the other strategies feedback becomes more important as some subjects explicitly attempt to learn the 'feel' of the task while others attend to the visual cue. As some indication of the importance of these strategies has been found here, although with very small numbers of subjects, it would appear that how subjects approach such a task as this affects the way in which it is learned and the importance of a concurrent visual feedback. It is clear however, that the general effect of such visual feedback is not like that in the bar pressing experiments, mainly because of the other options which are open to the subject in this situation which were not there in the previous one.

5.3 Experiment 7 Strategies used by subjects when learning to time a movement under two feedback conditions.

Introduction

Method

Subjects

Apparatus

Procedure

Results

A) Overall

B) Strategies
- i) Absolute error
- ii) Constant error
- iii) 'Speed' strategies
- iv) Movement pattern

C) Subjective ratings
- i) Accuracy
- ii) Confidence

Discussion

Introduction

In the previous experiment the subjects were not able to use a visual feedback cue to learn a fast movement; in fact, it appeared to upset their understanding of the task. For a slower movement there was little difference in the performance of subjects trained with AIF and those trained with TIF, in either practice or test conditions, the only difference being in the direction of error in the two second movement conditions, and this may mean that some subjects trained with AIF underestimated the length of the track during practice and test rather than that they were misled by the visual cue. There were some indications that the strategies used by the subjects in learning the task had affected the way in which the visual cue was used. For example, subjects who used the visual display to help them get a 'feel' for the task may be better in test than those who used it simply to control performance in practice. The strategy of counting which many subjects used may make the visual cue comparatively unimportant, except for the correction of the counting itself.

This experiment is basically a replication of the previous one, or at least of that part which concerned learning a two-second movement, as the results were not entirely expected and the classification of strategies was worked out part way through when it became clear which were salient points in subjects' accounts of what they did. The two second movement was retained and subjects were trained with either AIF or TIF. As the types of strategy used are now clearer it should be possible to assign strategy categories more easily and to question subjects as to whether they think the categorisation is an accurate one, for example, subjects could be asked which, if any, of the expected strategies they used.

The previous study indicated little difference between subjects in the two conditions when they estimated their own accuracy in test. This was not expected as subjects in a bar pressing task trained with AIF tended to feel they were inaccurate when the cue was removed. Asking subjects to rate their test accuracy should make it possible to investigate this subjective error estimation in a quantitative fashion.

In general it is hoped that some additional evidence will be found for the suggestion that a 'feel' of the movement strategy under AIF training is the most efficient of all methods of learning this task, as this would support suggestions that kinaesthesis is very important in timing tasks, especially when the movement is consistent, and that a strategy of 'watching the dots' will lead to increased accuracy in practice but less in test than other conditions, as is the case for a bar pressing task.

Method

Subjects

These were 24 undergraduate and post graduate members of the University of Leicester. There were 12 males and 12 females. Ages ranged from 19 to 26 years with a median of 21.

Apparatus

As in Experiment 6 except that the programme caused the continuous feedback to remain on the screen after the end of the trial rather than disappearing and returning.

Procedure

Subjects were randomly assigned to one of the two groups with 6 males and 6 females per group. They were then given the instructions as in Experiment 6. Again there were 5 baseline trials, 30 practice trials, five test and five retest trials. Feedback remained visible for 1.5 seconds after the end of each trial and the ITI was again 5 seconds. Procedure in general was as in the previous experiment.

After the test trials subjects were asked how they had attempted to learn the task and their replies were coded as 'counting', 'speed', 'feedback', or a combination of these. 'Counting' included rhythmic strategies 'speed' included 'feel' of the task and 'feedback' simply meant using the continuous feedback as a cue when to terminate the movement without attempting to code the target time. Subjects were asked if they agreed with the classification. They also answered two questions using a five point scale to rate their answers. The first question was "How accurate were you when the feedback stopped?" to be answered on the scale - 1: very accurate, 2: accurate, 3: fairly accurate, 4: inaccurate, 5: very inaccurate. The second question "How sure are you about this?" was answered on the scale - 1: very unsure, 2: unsure, 3: don't know, 4: sure, 5: very sure.

These questions were intended to investigate subjective accuracy and confidence and it was felt that members of the TIF group would rate their performance as more accurate and be more confident of this than would the AIF group whose use of the visual feedback might leave them unsure of the error weighting to be given to a response judged by proprioceptive feedback alone.

Retest began three minutes after the end of test so that all subjects were clear about the questions asked and their replies before they were tested again.

Results

A) Overall

The results of most interest in this experiment are those for the strategies used within the two feedback groups but overall analyses have been carried out to confirm the findings of Experiment 6.

Both absolute and constant error scores were analysed using a 2 x 4 ANOVA with type of feedback and stage of learning as the factors. For absolute error the pattern of the previous experiment was repeated (see Figure 16), and no differences were found between the types of feedback while the stages differed significantly (Table 58). A Tukey test showed that the baseline error scores were larger than those for any other stage and that the others did not differ that is, learning had taken place in both conditions. The interaction was not significant.

However, the baseline scores show a wide variation, so wide in fact that the variance of the conditions within the feedback types is not homogenous (F max = 23.56, (8,11) $p < 0.01$). Inspection of the results (Figure 16) shows that there is a difference between the practice scores of the AIF and TIF conditions. A test of the difference between practice and test scores for the two feedback types (equivalent to testing the interaction of type of feedback and test/practice error) was significant ($U = 20$ $p < 0.01$). This indicates that TIF subjects make less error in test than in practice while AIF subjects give opposite results. The actual test errors however, do not differ.

Figure 16. Mean percentage error (AE) for two types of feedback over four performance stages.

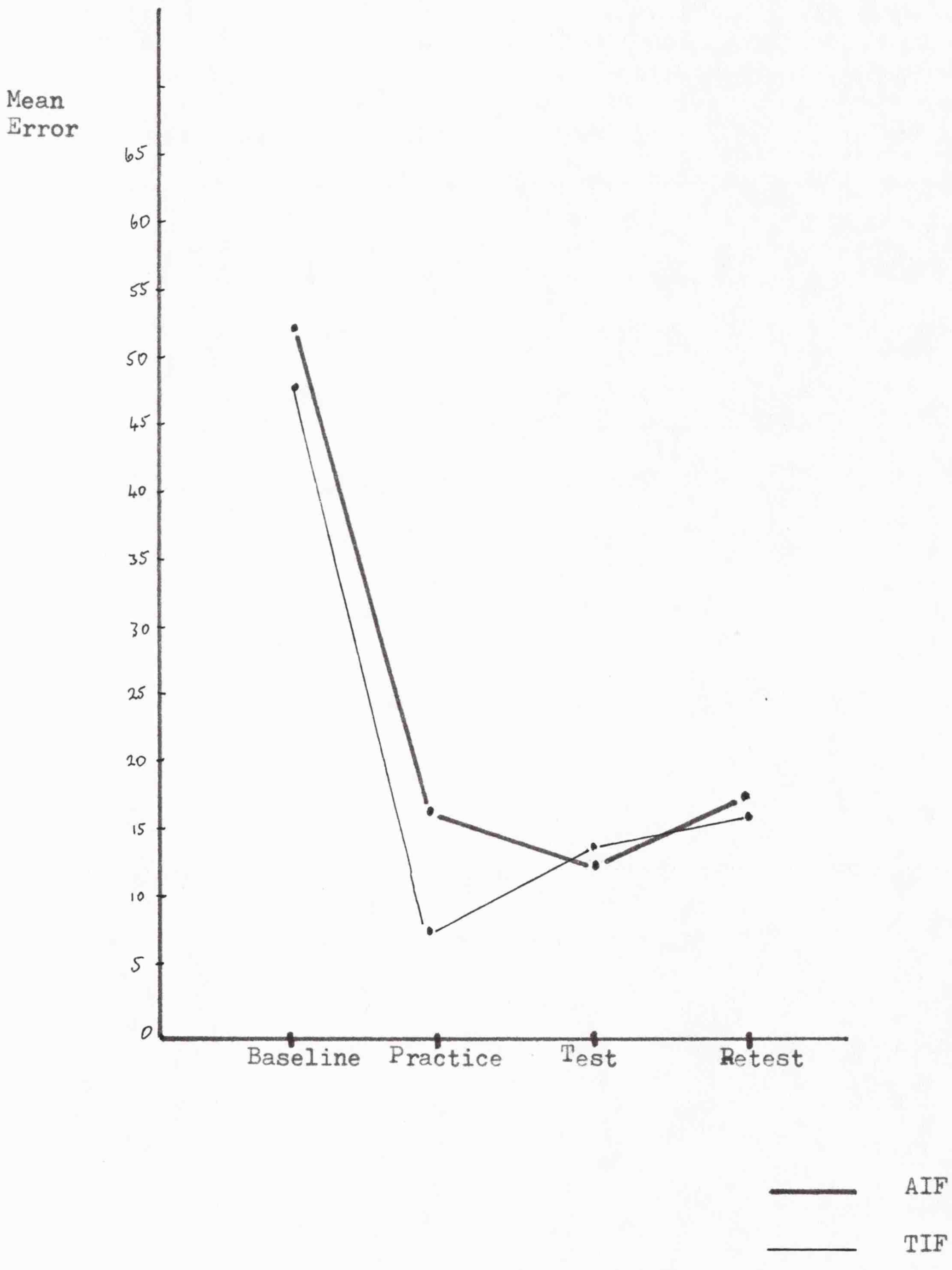


Table 58

Standard deviations of the absolute error means in Figure 16 and analysis of these means.

		Baseline	Practice	Test	Retest
AIF	S.D.	20.92	4.31	5.67	5.63
	Range	10.21- 77.00	3.45- 20.27	5.00- 26.60	7.90- 24.70
TIF	S.D.	17.83	4.40	4.69	6.28
	Range	13.10- 83.63	9.11- 24.04	3.23- 18.86	7.41- 31.36

Analysis

Source	DF	SS	MS	F	P
Between					
1) Feedback	1	249.55	249.55	1.43	NS
Subjects W. groups	22	3852.47	175.11		
Within					
2) Stages	3	24010.02	8003.34	73.43	**
1 x 2	3	324.66	108.22	0.99	NS
2 x Ss x groups	66	7193.15	108.99		
Total	95	35629.85			

For constant error the results were different from those from the previous experiment (Figure 17), especially for AIF subjects on test and retest. A 2 x 4 ANOVA showed that the types of feedback were not different in their effect on error, although the direction of error did differ between the stages due to the very short time used by most subjects in the baseline trials (Table 59).

The differences between experiments 6 and 7 were examined by Mann Whitney 'U' tests on test and retest scores for AIF subjects on the two occasions. Neither was significant (Test: U = 59), Retest U = 44 N1 = 12, N2 = 10).

B) Strategies

Subjects were assigned to strategy groups on the basis of their answers to the specific questions after test. All AIF subjects who reported using the feedback to control their responses (i.e. they said "I watched the dots" or equivalent), or who said that they did so in conjunction with other strategies were classified as "feedback" strategists while all others were classified as "non-feedback" strategists. There were 6 feedback and 6 non-feedback users and of the latter group 3 used speed strategies and three counting strategies.

For the TIF condition subjects who used a speed or feel strategy, either by itself or in conjunction with some counting, were classified as "speed" strategists, while those who only mentioned counting were classified as "counting" strategists. Again there were 6 subjects per group.

Analyses were carried out on the two feedback conditions separately with the exception of a comparison of AIF and TIF "speed" strategists. Again both absolute and constant error scores were considered.

Figure 17. Constant error scores for 2types of feedback over four performance stages.

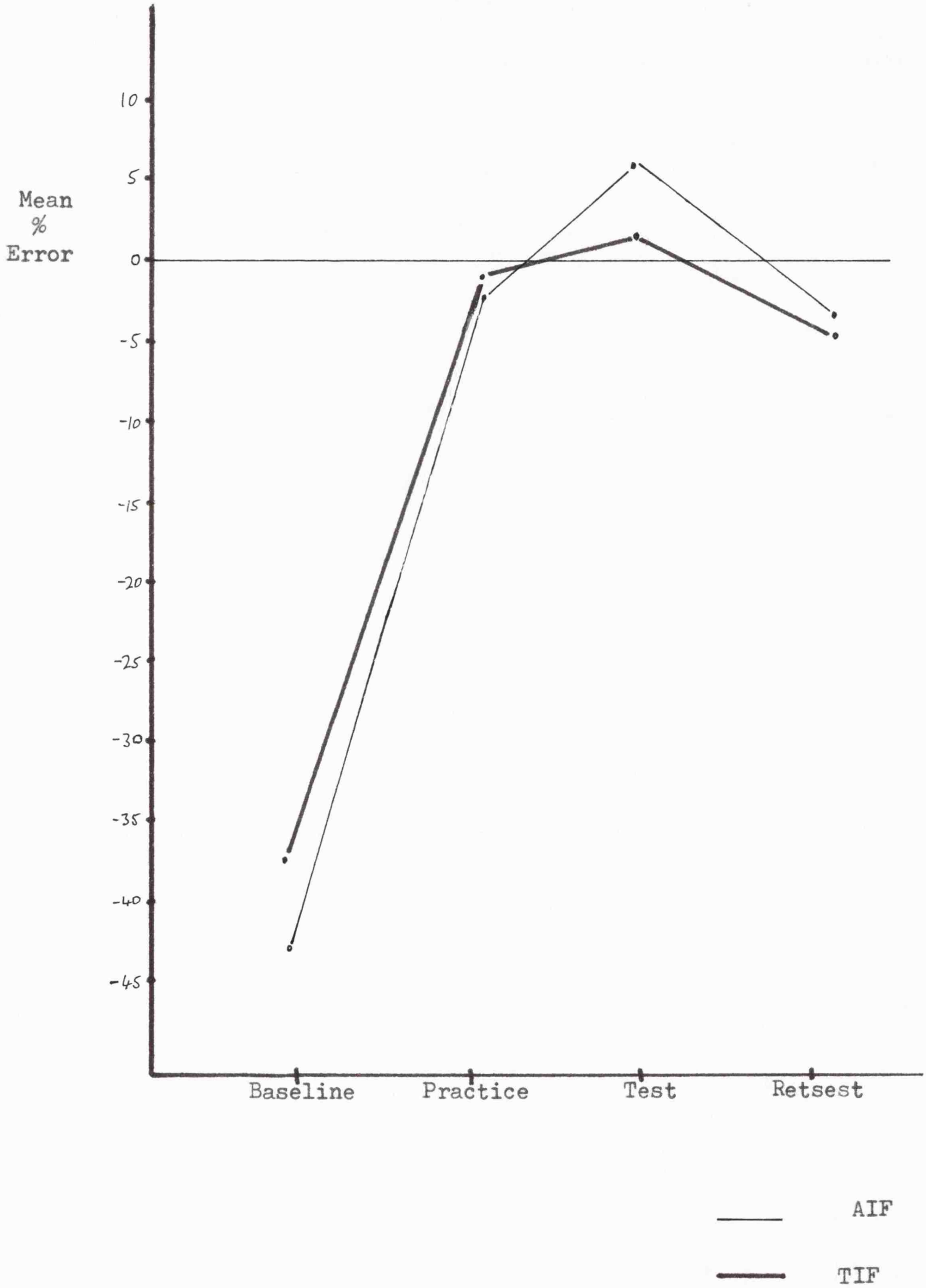


Table 59

Standard deviations of the constant error means in Figure 17, and analysis of these means.

		Baseline	Practice	Test	Retest
AIF	S.D.	22.15	2.85	8.32	13.89
	Range	-77.00- -6.53	-6.88- 1.10	-7.10- 22.80	-23.20- 24.70
TIF	S.D.	39.29	7.09	11.34	14.28
	Range	-69.23- 43.05	-15.66- 11.38	-17.23- 18.86	-31.36- 15.74

Analysis

Source	DF	SS	MS	F	P
Between					
1) Feedback	1	0.23	0.23	0.0004	NS
Ss within groups	22	12073.80	548.81		
Within					
2) Stages	3	30041.45	10013.82	32.81	**
1 x 2	3	301.19	100.40	0.33	NS
2 x Ss x groups	66	20143.14	305.20		
Total	95	62559.80			

i) Absolute Error

As all subjects made large errors in baseline performance the strategy analyses were carried out without including baseline data. Baseline/ test correlation coefficients for AIF feedback and non-feedback strategies were r = 0.03 and 0.26 respectively. For TIF counting and speed strategies there were r = -0.16 and 0.03 respectively. There does not appear to be a relationship between overall error in baseline and that in test.

Mean absolute error scores for the strategies in the AIF condition are presented in Table 60. A 2 x 3 ANOVA with repeated measures on the last factor (stage of learning) showed that there was no difference between the strategies and that the stages differed. The interaction was not significant. The type of strategy used by AIF subjects in this experiment does not seem to affect their absolute error scores throughout practice, test and retest.

For the TIF strategies AE scores and the results of a 2 x 3 analysis of variance are presented in Table 61. Neither strategy nor stage of learning produced significant differences in this analysis. There was no interaction. The difference between the AIF and TIF analyses is that in the former the stages differ due to the low practice error score in the AIF condition.

ii) Constant Error

Constant error scores for both types of feedback also show no differences between the strategies in either feedback condition (Tables 62 and 63).

Table 60 — Mean AE scores for feedback - and non-feedback - strategies in the AIF conditions: and analysis of these means (practice, test and retest).

		Baseline	Practice	Test	Retest
Feedback Strategy	Mean	54.67	6.12	11.72	18.03
	S.D.	13.28	2.08	3.29	5.66
	Range	32.40-77.00	3.45-9.72	7.00-15.30	7.90-24.70
non-feedback strategy	Mean	41.36	9.14	15.06	14.48
	S.D.	24.70	5.31	6.93	5.01
	Range	10.21-73.90	4.03-20.27	5.00-26.60	7.92-20.90

Analysis of practice, test, and retest means for the two strategies.

Source	DF	SS	MS	F	P
Between					
1) Strategy	1	7.88	7.88	0.27	NS
Ss within groups	10	289.00	28.90		
Within					
2) Stage	2	463.49	231.74	7.48	*
1 x 2	2	90.70	45.35	1.46	NS
2 x Ss within groups	20	619.97	30.99		
Total	35	1481.05			

Table 61 — Mean AE scores for 'speed' and 'counting' strategies in the TIF condition; and analysis of some of these means.

		Baseline	Practice	Test	Retest
	Mean	47.67	15.86	13.74	19.34
'Speed'	S.D.	22.32	5.43	5.16	6.09
	Range	13.10-83.63	9.11-24.04	3.23-18.86	11.18-31.36
	Mean	56.97	16.85	11.47	14.50
'Counting'	S.D.	9.89	2.94	3.86	5.47
	Range	42.95-69.23	11.00-20.53	7.13-18.49	7.41-25.17

Analysis of means for practice, test, and retest

Source	DF	SS	MS	F	P
Between					
1) Strategy	1	33.41	33.41	0.69	NS
Ss within groups	10	480.01	48.01		
Within					
2) Stage	2	140.50	70.25	0.80	NS
1 x 2	2	45.37	22.68	0.26	NS
2 x Ss x groups	20	1736.90	86.84		
Total	35	2436.19			

Table 62 — Mean CE scores for feedback and non-feedback strategies in practice, test and retest in the AIF condition; and analysis of these means.

		Practice	Test	Retest
	Mean	-3.63	6.63	-1.73
	S.D.	2.15	9.73	10.79
Feedback	Range	-5.83-	-5.40-	-20.9-
Strategy		-0.36	22.80	12.90
	Mean	-1.92	4.85	-6.83
Non-	S.D.	3.22	6.49	16.02
feedback Strategy	Range	-6.88-	-7.10-	-20.6-
		1.10	12.80	24.7

Analysis

Source	DF	SS	MS	F	P
Between					
1) Strategy	1	28.6	28.6	0.15	NS
Ss within groups	10	1918.48	191.85		
Within					
2) Stage	2	696.52	348.26	5.66	*
1 x 2	2	66.34	33.17	0.54	NS
2 x Ss x groups	20	1231.08	61.55		
Total	35	3941.28			

Table 63 — Mean CE scores for two strategies in the TIF condition for practice, test and retest; and analysis of these means.

		Practice	Test	Retest
Counting	Mean	-3.81	-2.40	-9.93
	S.D.	6.37	9.38	9.09
	Range	-15.66- 3.28	-17.23- 7.76	-25.17 3.08
Speed	Mean	-0.86	5.66	-2.01
	S.D.	7.29	11.69	17.14
	Range	-12.27- 11.38	-16.79- 18.86	-31.36- 15.74

Analysis

Source	DF	SS	MS	F	P
Between					
1) Strategy	1	386.39	386.39	1.38	NS
Ss within groups	10	2802.17	280.22		
Within					
2) Stage	2	347.24	173.62	2.56	NS
1 x 2	2	49.53	24.76	0.37	
2 x Ss x groups	20	1353.99	67.70		
Total	35	4939.32			

iii) 'Feel' of movement strategies.

As the previous experiment had suggested that AIF subjects who used a 'speed' or'feel of movement' strategy were more accurate in test than TIF subjects with the same strategy, those subjects who had reported using such a strategy and nothing else were compared across the feedback conditions. Unfortunately there were only three subjects in each condition who used this strategy alone so no firm conclusions can be drawn. Mann Whitney U tests on AE scores for practice and test were not significant, (practice U = 2: test U = 4).

iv) Movement pattern

The position of the slider switch was measured at 200 msec intervals as in the previous experiment so that changes in speed of movement could be calculated. It was felt that those AIF subjects who reported that they depended on the feedback would make an initial fast movement and then wait until the display indicated that the time was almost up before shooting the slider home. AIF subjects who used other strategies would not be expected to do this so they would have smaller scores as their movement pattern would deviate less from the pattern of movement at a regular rate. AIF and TIF mean deviation scores are shown in Table 64. There was no difference between the conditions at any stage of practice.

A comparison of the deviation scores for the second fifteen practice trials was made between subjects in the two AIF strategy groups (Table 65). By this stage of practice subjects are able to perform reasonably accurately and their response style has been established. A Mann Whitney U test on these scores gave U = 8 (p = 0.066) and three of the six subjects who reported using the feedback performed as was expected - they waited until the cue had

Table 64 — Mean sums of squares scores for two types of feedback, in 15 trial blocks.

		AIF	TIF	t
1st 15 practice trials	Mean	0.0269	0.0272	0.0169
	S.D.	0.0420	0.0238	
2nd 15 practice trials	Mean	0.0092	0.0079	0.2932
	S.D.	0.128	0.0042	

Table 65 — Mean sums of squares scores for two strategies in the AIF condition; in 15 trial blocks.

		Feedback strategy	Non-feedback strategy	U
1st 15 practice trials	Mean	0.0201	0.0339	17
	S.D.	0.0158	0.0565	
2nd 15 practice trials	Mean	0.0154	0.0030	8
	S.D.	0.0156	0.0030	

almost reached the target then shot the slider home (See Figure 18). However as one subject in the same group made the smoothest movements of all AIF subjects it remains possible that subjects' reports of their strategy are not accurate estimations of what they actually did.

If subjects' reports of strategy do not represent the way in which they performed during practice, the smoothness of their movements in the second 15 practice trials may show more clearly whether they waited for the feedback cue (i.e. were 'feedback' strategists), or not. It could be expected that those subjects who did wait would have the largest sums of squares scores for the movement and also the largest error scores after the cue was removed. A correlation between the SS movement scores and test error however, showed this not to be the case (rho = -0.42 N.S.). Although the correlation was in the direction opposite to that expected, so that those subjects with small SS scores (i.e. smooth movement) tend also to make large error, this is not a significant relationship. There is no evidence that AIF subjects' mode of practice affects their accuracy in test.

C) Subjective ratings

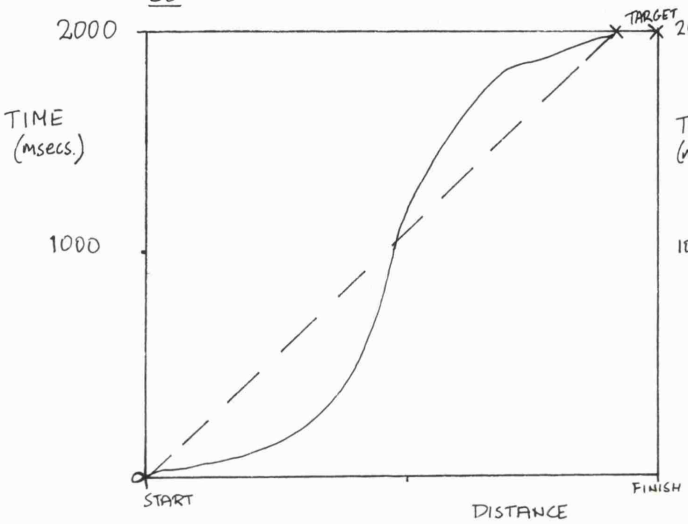
i) Accuracy

Subjects' ratings of their accuracy were very similar for both AIF and TIF subjects (Table 66). Most subjects chose the middle category. Because 18 of the 24 subjects used this category it was impossible to relate objective and subjective accuracy. A 't' test on the means of AIF and TIF subjective ratings gave t = 0.50 which is not significant ($p<0.05$).

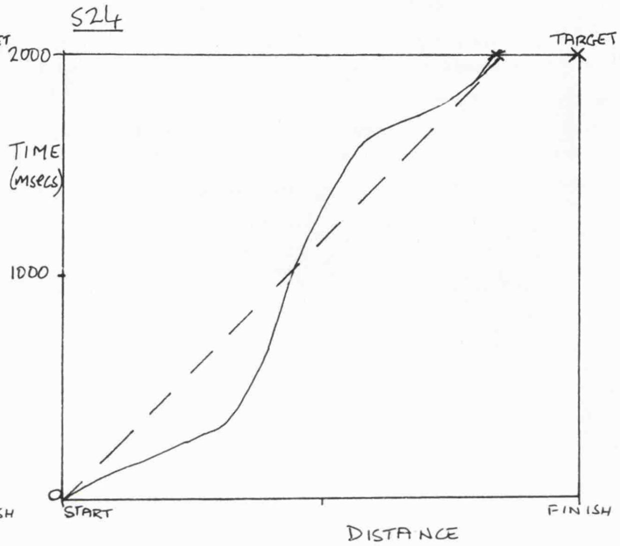
Figure 18 Individual subjects' movement patterns for the second 15 practice trials, AIF 'feedback' strategy - expected and unexpected movement patterns.

Expected patterns

S8

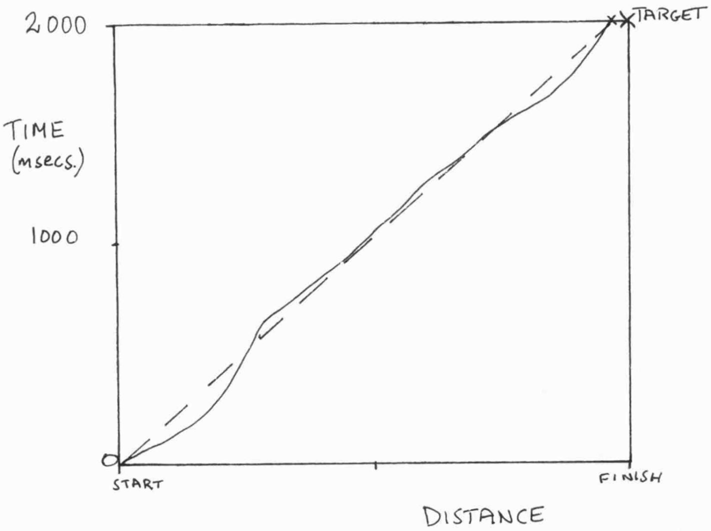


S24



Unexpected pattern

S17



Pattern found with smooth movement	— — —
Actual movement pattern	———

Table 66 Frequency of accuracy ratings for AIF and TIF trained subjects

Category :	1 & 2 (accurate)	3	4 & 5 (inaccurate)
AIF	1	10	1
TIF	3	8	1

ii) Confidence

For subjective confidence ratings subjects in the AIF condition were evenly divided between 'sure' and 'unsure'. TIF subjects tended to report 'unsure' more often (Table 67), but this was not significant (X^2 = 0.47).

Table 67 Frequency of confidence ratings for AIF and TIF trained subjects

Category :	1 & 2 (sure)	3	4 & 5 (unsure)
AIF	6	0	6
TIF	3	1	8

These results are similar to those in the previous experiment. With a time learning task subjects trained with a continuous visual cue do not differ from those trained with a terminal cue in their estimates of accuracy or their confidence in their test performance.

Discussion

The results of this experiment confirm those of the previous one that, when subjects are required to make a movement in a time of two seconds they do so equally well whether they have terminal or concurrent visual feedback. In addition, they rate their error in a similar way, and are equally confident of their accuracy in test.

The strategies which the previous experiment suggested were important in learning and retention of the task have failed to affect performance in either practice or test. There is no difference between those subjects who report that they used the visual cue and those who tried to learn the 'feel' of the task, and a 'feel' of movement strategy with AIF does not lead to better retention than it does with TIF.

There are many drawbacks to the method of obtaining strategies used here. Subjects may not in fact be aware of the strategy they were using and although attempts were made to ensure that they knew what they meant when they described the strategy, the evidence from the patterns of movement of AIF trained subjects suggests that subjects may apply very different labels to similar responses. Those subjects who reported that they used the visual cue, but yet made a smooth movement do not appear to use the cue as one would expect - are they perhaps unconscious 'feel' of movement strategists?.

Using the smoothness of movement as an indication of dependence on the feedback cue is not useful when error in test is considered. There is no relationship between these two. It appears that even performance measures of strategies, assuming that subjects' reports can't be trusted, do not differentiate between subjects who could be expected to depend on the visual cue and perform badly without it, and those who use a counting or kinaesthetic method to time the movement.

The prevalence of counting or other rhythmic strategies may be of great importance. Subjects who use such strategies are not dependent on a visual cue, as has already been stated, they may therefore obscure any differences which exist between AIF and TIF test performances. If this strategy could be ruled out and subjects were forced to use feedback, either visual or kinaesthetic, to control their movements, differences between the two types of training might appear.

The removal of auditory feedback is also important. Although subjects do not mention this type of feedback as a method of learning the task, its irrelevance should not be taken for granted and it should be removed in order to show the effects of the types of training as clearly as possible.

When these factors are removed or controlled it may become possible to decide whether or not a timing task can be acquired using AIF, and if it can, whether this is due to the fact that timing depends on kinaesthetic mediation so that the concurrent visual cue does not make any difference to the learning of the task. On the basis of the present evidence it is impossible to decide whether or not a concurrent visual feedback cue can distract subjects from kinaesthetic feedback, or subtly distort that feedback and delay the learning of the task.

5.4 Experiment 8 — The effects of a secondary verbal task on the learning and retention of timed movements.

Introduction

Method

Subjects

Apparatus

Procedure

Instructions to subjects

Results

A) Absolute error

B) Constant error

C) Variable error

D) Subjective error

Discussion

Introduction

The use of a counting strategy by many subjects in the time tracking task has made it difficult to interpret the results of no difference between the AIF and TIF training conditions. A verbal cue can be rehearsed whether continuous visual feedback is present or not, and the visual feedback may act terminally to change or confirm the verbal code. In this case response-produced feedback would not be necessary for the on-going control of the movement, as the movement duration could be matched to the duration of a verbal pattern. This may of course mean that visual continuous feedback is not important in any task which is verbally controlled, although it would be expected that if a task were well-learned verbal control would drop out.

The effects of visual action feedback on the learning and performance of a bar pressing task raise questions about the relationship of vision to other feedback systems, and to the establishment of automatic skilled control of movement. If verbal mediation is present it will disrupt these relationships and make it difficult to identify the effects of duration and accuracy of movement. If counting could be prevented when subjects learn to make a movement in two seconds, it might be found that the visual cue does prevent accurate reproduction of the timed movement.

In order to change the time learning task to one in which only kinaesthetic and visual cues would be used to control performance it was decided that a simple shadowing task should be performed as a secondary task. This was intended to prevent counting while not interfering with the acquisition of the primary task.

There is some evidence that this task should not place too great a strain on the subject's capacity. Greenwald (1972) and Greenwald and Shulman (1973) have suggested that when two tasks are 'ideomotor compatible' they can be performed simultaneously with no interference between them. Greenwald's (1972) ideomotor theory holds that an action is encoded in the form of an image of its sensory feedback. A relationship of ideomotor compatibility between stimulus and response is defined as one in which the stimulus resembles the feedback from the response, e.g. if a word heard is responded to by the same word being spoken. Greenwald uses another task, that of making a movement in the direction of an arrow, which he regards as ideomotor compatible although he acknowledges that for this task it is necessary to assume that spatiality of a visual positional cue resembles in some way the spatial component of sensory feedback from movement.

In general, this position reflects qualifications which have been made to the idea of man as a limited capacity information processing channel (Welford 1968). Rather than restricting the throughput of the channel to one item at a time so that the processes of attention were occupied sequentially (Broadbent 1958), several workers have suggested that other characteristics of the task or tasks, such as stimulus - response compatibility may affect the simultaneous processing of two types of information (e.g. Allport, Antonis, and Reynolds 1972).

Although shadowing of a piece of continuous prose is supposed to fill the limited processing channel, Allport et al. (1972) showed that shadowing and other tasks could be performed simultaneously without loss of accuracy. Shaffer, (1975) suggests that this result does not imply an unlimited channel but that the contents of that channel are passed to a buffer store in large enough units for performance to be smooth and undisturbed. Whether that is the case or not this evidence indicates that adding a shadowing task should not interfere with the performance of a simple motor task, or the perception of visual cues.

In Greenwald's (1972) paradigm a task must be separated into stimulus and response so that their compatibility can be estimated. This is rather difficult in the time learning task. The cue marks are presumably the stimulus for the response of moving the slider and these are not obviously compatible. However, Greenwald (1972) suggests that efficient time sharing could be obtained even if one of the two tasks is not ideomotor compatible, because the compatible nature of one task would mean that it placed very little burden on limited capacity processing. Thus it was hoped that interference with the primary task from simple shadowing would be minimal and that the effects of continuous visual feedback would be seen more clearly as there would be no possibility of counting being used as a strategy.

Before the experiment was carried out a few subjects were asked to perform the two tasks and to comment on the difficulty of performing both at once. They reported that after a short exposure to the shadowing task it required little attention. One subject said he performed it 'automatically' which would support the suggestion that little strain was made on subjects' performance capacity.

In the experiment itself there were two conditions, AIF and TIF, in which subjects were required to perform as in the previous experiments but at the same time they shadowed a list of words.

Method

Subjects

These were 20 undergraduates of the University of Leicester.

There were equal numbers of males and females. Ages ranged from 19 to 26 with a median of 21. All subjects were naive to this task and were right handed. Handedness was limited in order to minimise variation due to hemispheric differences in verbal and motor tasks for left and right dominant people.

Apparatus

The slider equipment was that used in experiments 6 and 7. There were 6 dots per cm of visual display for both AIF and TIF conditions.

In addition a Ferrograph tape recorder was used to present a continuous list of words to the subjects through earphones. The words were all one or two syllable ones and were chosen at random from the common words rated as A or AA by Thorndike and Lorge (1944), i.e. words having at least 50 occurrences per million as calculated by those authors. Proper names were not included.

The words were spoken by a female voice at a steady rate of approximately one every two seconds. There were three hundred and sixty five words on the tape giving a total time of approximately twelve minutes.

Procedure

As the subject was required to shadow continuously to the end of the test trials all instructions had to be given before any responses were made. Subjects were told that they would first estimate a two second movement, then be taught to do it and then be required to show what they had learned.

There were two feedback conditions AIF and TIF. Subjects were randomly assigned to these with equal numbers of males and females in each group. Each subject began shadowing and after 2 minutes when s/he had indicated some confidence in the shadowing made five estimates of a two second movement, waiting for the cue marks to initiate each trial. When the teletype indicated that baseline was over by producing a nonsense message each of the succeeding trials produced the appropriate feedback. After 30 such trials the same auditory cue preceded the removal of the feedback and the beginning of the 5 test trials. The inter trial interval was 5 secs. and feedback remained on the screen for 1½ secs. in both conditions. There was a two minute interval between test and retest during which the tape recorder was turned off. Omissions or gaps in the list of words shadowed were noted but errors in identification were not as these were difficult to detect. Before retest the tape recorder was switched on and shadowing recommenced.

Instructions to subjects were as follows:

<u>AIF group</u>

"Your task in this experiment is to learn to move this switch from here to here (pointing) in two seconds. First I would like you to make an estimate of a two second movement by moving the slider in what you think is two seconds. When the switch reaches the end of the track the two marks on the screen will disappear, return the slider to the starting position and wait for them to reappear, then repeat the movement in what you think is two seconds. Always wait for the two marks to appear on the screen before moving the switch.

When you have done this a few times the teletype will make a noise. After this you will learn to make the movement in two seconds. * As you move the slider a line will grow across the screen from the mark on the left. It grows at a steady rate and represents time. When you reach the end of the track it stops. If you can stop it at the second mark you will have made the movement in two seconds**. If it does not reach the second mark your movement was too fast (did not take long enough), if it goes past it your movement was too slow (took too long). Return the slider to the starting position and wait for the cue marks before starting again.

When you have practised in this way for a considerable time the teletype will make the noise again and the line will no longer appear. You must then try to reproduce the movement in the time which you have been learning. Remember you are to learn to make the movement in two seconds so that you can reproduce it accurately by yourself."

Is that clear? (If not explain further otherwise continue)

"I also want you to listen to the words coming through these earphones. There will be a word followed by a pause then another word. I want you to repeat each word in the pause which follows it. If you are unsure about the word don't worry, try to make the sound which you think you heard."

(After practice shadowing for 2 minutes)

"Now I want you to learn the two-second task while repeating the words. Do you remember what to do? (Instructions were repeated if necessary). First estimate 2 seconds then use the line to learn it then reproduce it by yourself. Don't worry about the words, let them flow. Any questions?"

TIF group

* to ** replaced with

"When you have moved the slider in what seems to be two seconds a line will appear on the screen telling you how accurate you have been. If it reaches the second mark you will have made the movement in two seconds."

Before retest subjects were told:

"Now the last few trials will be repeated. Move the slider in two seconds, trying to remember what you have been learning. The line will not appear. Begin repeating the words and then start the movements when you are ready.

Results

Absolute error

Mean AE scores for the two feedback conditions are presented in Figure 19 and further information about these means and the results of a 2 x 4 ANOVA performed on them are given in Table 68. Again stage of training was a significant variable and there was a significant interaction between stage and type of feedback, although there was no difference between the types of feedback. While baseline error is clearly larger than that at other stages, it is not so easy to interpret the interaction as the groups change relative position several times. The TIF subjects were more accurate than AIF subjects in baseline but this accuracy is reversed during practice. Subjects were more accurate when a visual cue was present during practice than they were when they have to choose the time of movement for themselves and wait for feedback. During test the groups were equally accurate but in retest the TIF subjects were

Figure 19. Mean absolute error scores for two feedback conditions.

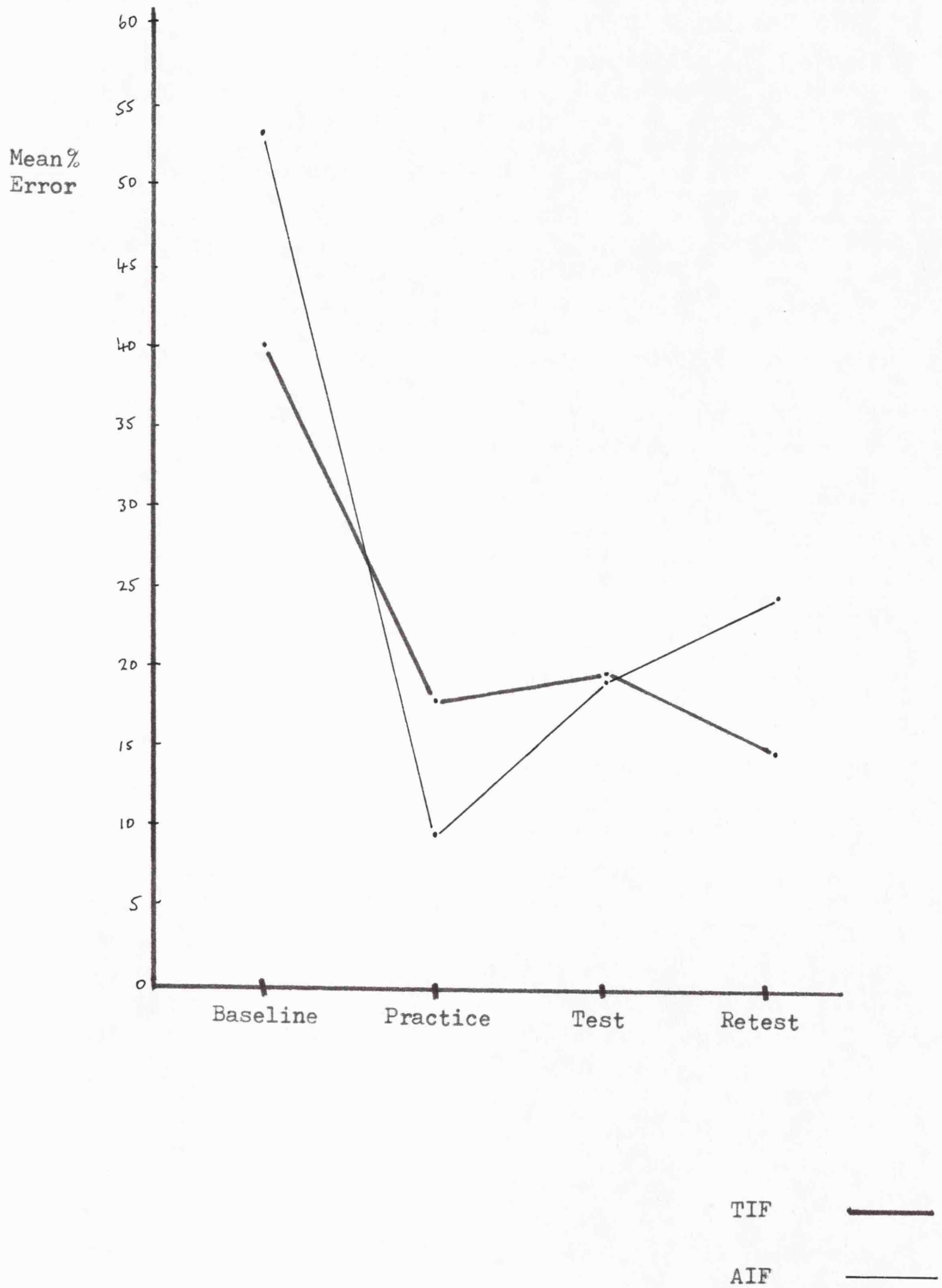


Table 68 Standard deviations of the AE means in Figure 19 and analysis of those means.

		Baseline	Practice	Test	Retest
AIF	S.D.	15.89	4.56	9.24	14.02
	Range	27.30- 68.50	4.32- 20.46	5.90- 32.80	7.20- 52.50
TIF	S.D.	16.42	5.25	8.25	7.98
	Range	18.41- 59.41	9.03- 26.05	8.00- 37.20	4.10- 25.10

Analysis

Source	DF	SS	MS	F	P
Between					
1) Feedback	1	265.90	265.90	0.87	NS
Ss within groups	18	5519.70	306.65		
Within					
2) Stage	3	13324.77	4441.59	55.48	***
1 x 2	3	1379.64	459.88	5.74	**
2 x Ss x groups	54	4322.80	80.05		

more accurate than the AIF subjects. This is confirmed by a 2 x 3 ANOVA of the same data with the baseline omitted, in which the interaction of the two factors is significant (Table 69). An analysis of covariance with baseline scores as the covariate confirmed the result of no difference between the feedback conditions. An analysis of the main effects in the interaction of type of feedback and stage of learning, indicated that the conditions differ in size of error on retest and that AIF scores change over practice, test and retest while TIF do not.

These results are more in agreement with those from the bar pressing task, in that AIF subjects perform slightly more accurately in practice than do TIF subjects, i.e. they use the feedback to guide responses. However there is still a high overall error in practice for the AIF condition. When the errors in practice are plotted over 5 trial blocks it can be seen that the two groups are consistently different in the amount of error produced, although even for the AIF condition a learning curve appears (Figure 20).

The practice error found in Experiment 6 is also shown on Figure 20, as this is quite different from that which is found when counting is removed. When TIF subjects are unable to count they make larger errors in practice. This is confirmed by a Mann-Whitney 'U' test on absolute error in practice in the two experiments, which was significant ($U = 23$ $p < 0.05$). A similar test on AIF practice error in the two experiments was not significant ($U = 46$ $p > 0.05$).

Removing the possibility of a counting strategy by requiring all subjects to shadow while performing the movement task means that subjects trained with terminal feedback find it difficult to

Table 69a

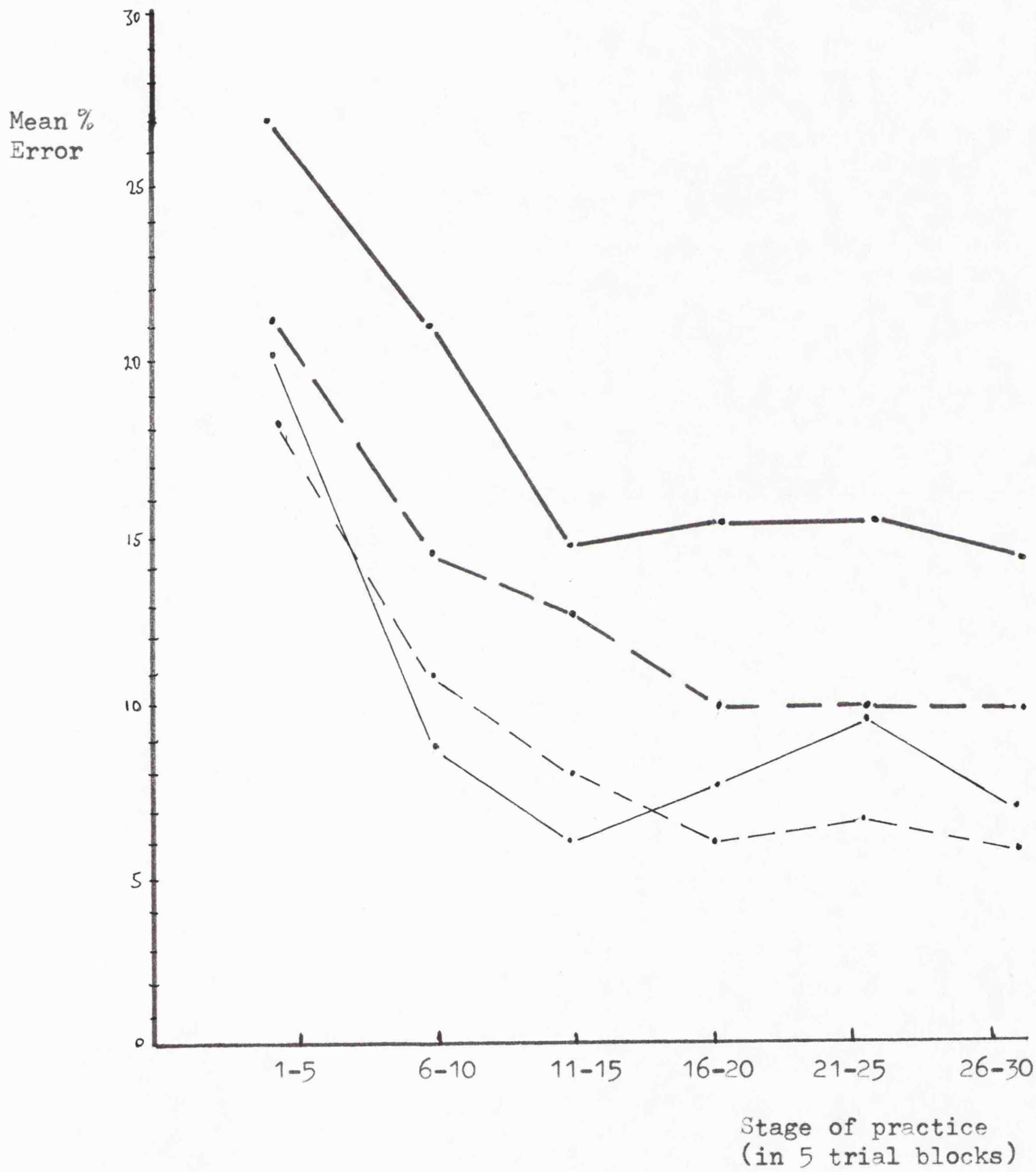
Analysis of AE error scores for practice, test and retest, with baseline as a covariate.

Source	DF	SS	MS	F	P
Between					
1) Feedback	1	4.80	4.80	0.03	NS
Ss within groups	18	2929.42	162.75		
Within					
2) Stage of learning	2	391.67	195.83	4.17	*
1 x 2	2	809.15	809.15	8.61	**
2 x Ss x groups	36	1691.22	46.98		
Adjusted values					
1) Feedback	1	95.27	95.27	0.85	NS
Ss within groups	17	1912.16	112.48		

Table 69b — Analysis of the main effects in the interaction in Table 69a.

Source	DF	SS	MS	F	P
Between					
1 at 2_1	1	305.15	305.14	3.57	NS
1 at 2_2	1	1.50	1.50	0.18	NS
1 at 2_3	1	507.23	507.23	5.93	*
Within cell	54	4620.78	85.57		
Within					
2 at 1_1	2	1036.43	518.22	11.03	*
2 at 1_2	2	164.67	82.34	1.75	NS
2 x Ss x groups	36	1691.47	46.99		

Figure 20 **Absolute error in practice in AIF and TIF conditions: Experiments 6 and 8.**



	TIF	AIF
Expt. 8	——— (heavy solid)	——— (light solid)
Expt. 6	— — — (heavy dashed)	- - - (light dashed)

learn the task. They do however, retain it quite well. Subjects trained with a continuous visual cue are not less accurate in practice when counting is prevented, they are able to use the cue to guide their performance, although perhaps not so accurately as would be expected with such a cue. There is a slight drop off in accuracy when the cue is removed and this is greater in retest. However the two training conditions do not lead to differences in accuracy immediately after the removal of augmented feedback, as they do with a bar-pressing task.

Constant Error

The constant error scores are plotted in Figure 21. These are quite unlike those found in previous experiments and a check on the homogeneity of the subjects within groups variance for the two conditions indicated that $F\ max = 6.20$. As the tabled value for $F\ max_{.05}(2,9)$ is 4.03 the hypothesis of homogeneity was rejected. Differences between the conditions were small and there was no regular pattern to the results. A further inspection of the actual scores indicated that there were large over- and under-estimations in baseline scores and that these were cancelling each other out in the groups means. Subjects were therefore reassigned to under- or over- estimation categories within each feedback condition. One subject could not be so assigned as his mean baseline error score was 0.9 and this did not qualify as either over- or under-estimation. This left 5 subjects for each of the AIF estimation classes, 5 for the TIF underestimation group, and 4 for TIF over-estimation. The CE scores for these four classes are shown in Figure 22.

When subjects are divided depending on the direction of their

Figure 21. Constant error means for two feedback conditions.

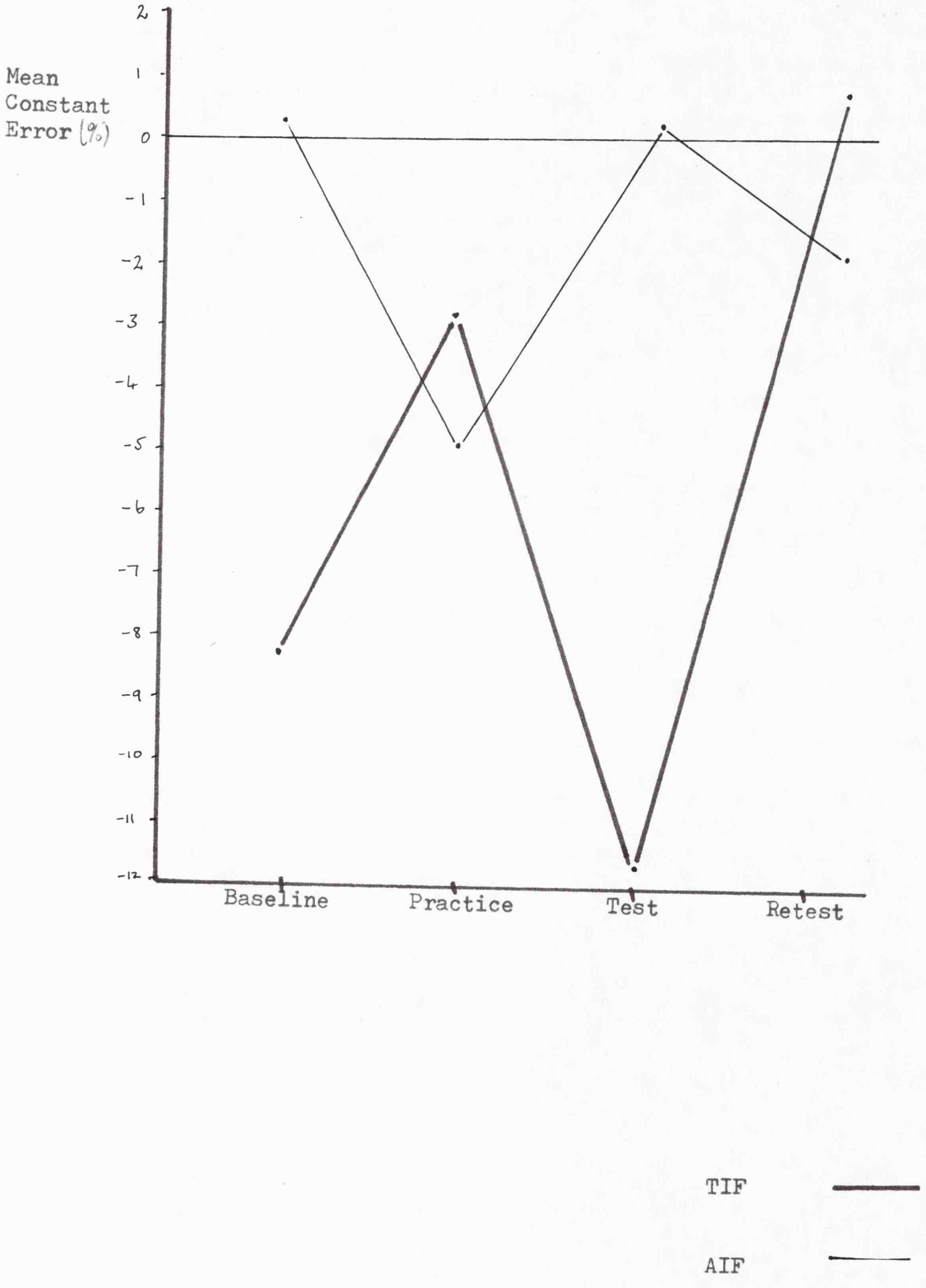
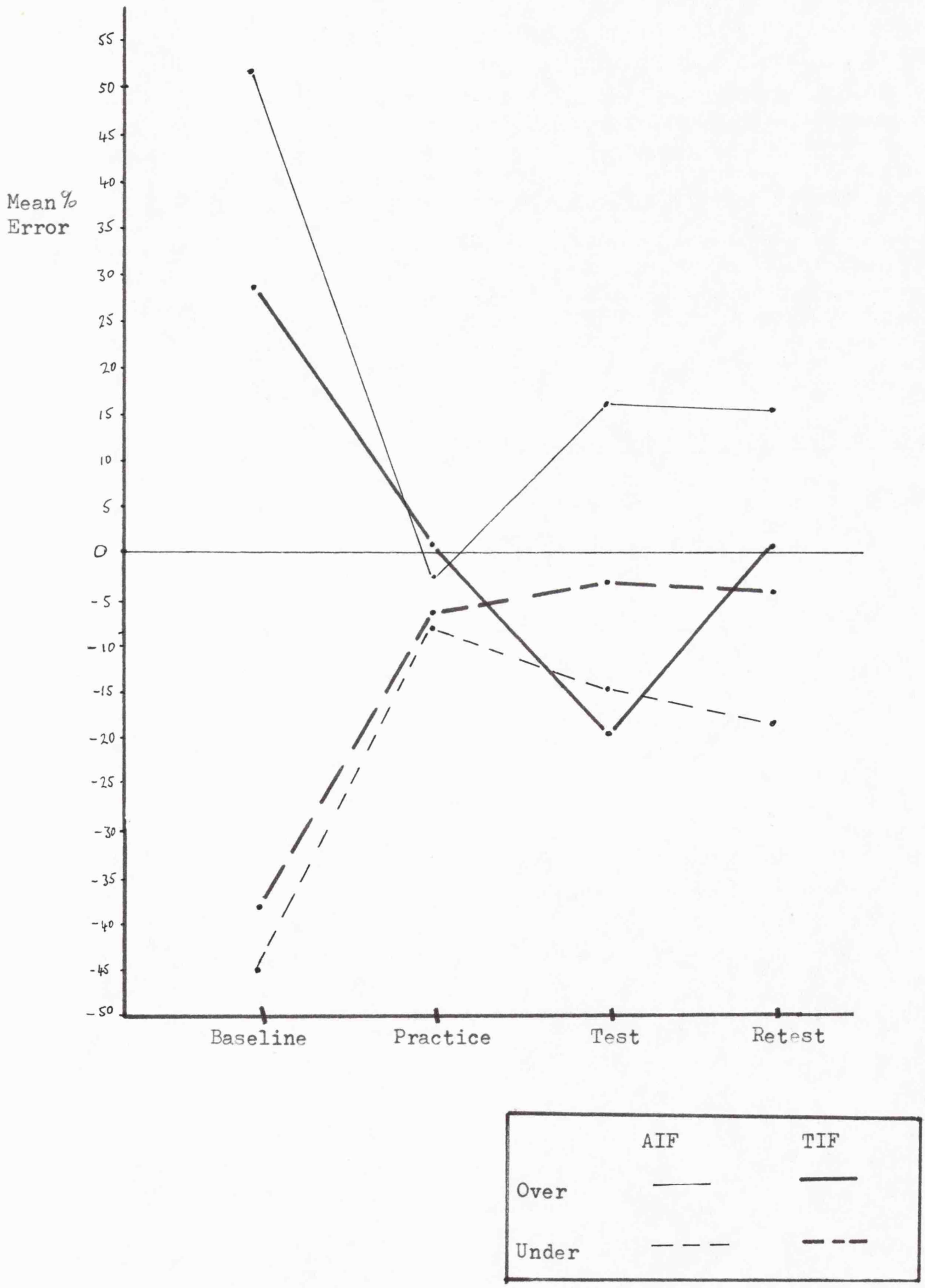


Table 70 Standard deviations of the means in Figure 21.

		Baseline	Practice	Test	Retest
AIF	S.D.	54.94	5.39	19.94	26.18
	Range	-68.40- 69.20	-16.03- 2.47	- 32.80- 28.80	-52.50- 32.00
TIF	S.D.	34.93	6.08	15.63	15.09
	Range	-59.40- 49.40	-15.98- 4.98	-37.20- 14.20	-24.10- 23.70

Figure 22 Constant error means for under and over estimators, in two feedback conditions.



initial error the results are more similar to those found in previous experiments. AIF over-estimators can be seen as a mirror image of AIF underestimators, indicating that subjects return to the direction of their baseline error. TIF results are not so easily explained but there is a tendency for TIF subjects to err in the direction opposed to their baseline error, at least in test. This is confirmed by the correlations found between baseline and test and retest scores (Table 71).

Table 71 Correlations between CE scores in baseline and those in test and retest: Spearman rho.

	Baseline/Test	Baseline/Retest
AIF	0.94**	0.82**
TIF	-0.56*	0.21

This result indicates that TIF subjects learn to correct their original error and overcompensate in test, i.e. they have learned that they tend to make movements which are too long so they err in the other direction. AIF subjects on the other hand, appear to regress in the direction of their original error. This is possibly related to the fact that they could depend on the feedback and did not need to actively choose to correct the error from the previous trial.

Variable Error

Variable error scores are plotted in Figure 23 and further information and results of analysis are given in Table 72. As expected, there is a decrease in response variability over time. TIF subjects are more variable than AIF subjects in practice,

Figure 23. Mean variable error scores for two types of feedback at four stages of performance.

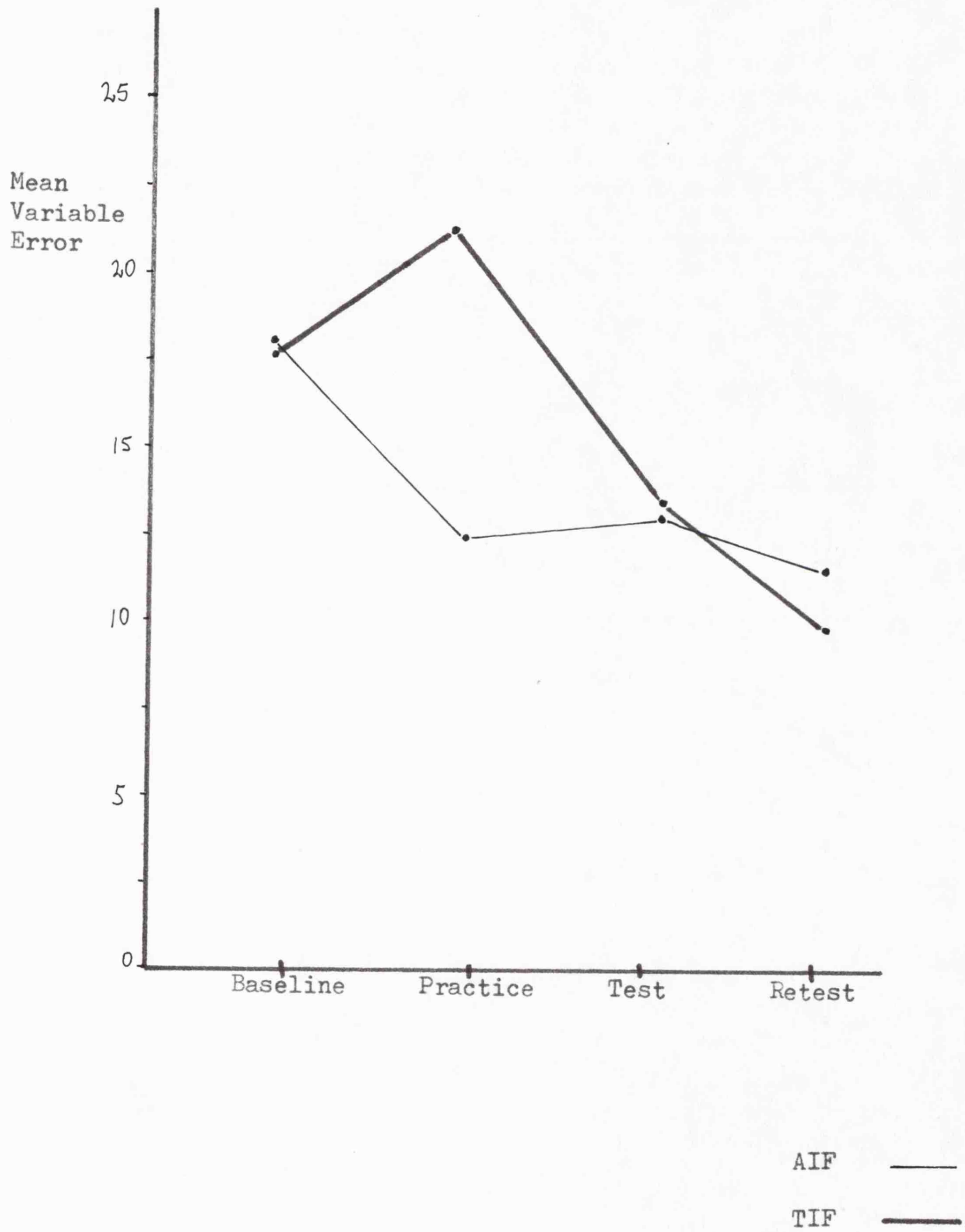


Table 72 Standard deviations of the VE means in Figure 23, and analysis of those means.

		Baseline	Practice	Test	Retest
AIF	S.D.	8.50	5.65	4.57	7.42
	Range	4.09- 27.32	5.25- 22.76	8.09- 21.65	7.03- 33.52
TIF	S.D.	12.08	6.15	3.81	5.36
	Range	3.26- 43.03	11.46- 33.55	6.89- 20.18	2.96- 17.89

Analysis

Source	DF	SS	MS	F	P
Between					
1) Feedback	1	43.03	43.03	0.92	NS
Ss within groups	18	841.50	46.75		
Within					
2) Stage	3	787.53	262.51	4.39	**
1 x 2	3	330.30	110.10	1.84	NS
2 x Ss x groups	54	3230.28	59.82		

although this difference just failed significance using Cicchetti's Tukey test. If the baseline is omitted the interaction between type of feedback and stage of learning is significant (Table 73), that is, variability of response, which is greatest in TIF practice, becomes less over time, and this does not occur in the AIF condition. This finding lends some support to the view that AIF subjects behave differently in practice from TIF subjects, using the continuous feedback cue enables them to perform more accurately and more consistently in practice than TIF subjects do.

Subjective error estimates

It was suggested that AIF subjects would not make as accurate a judgement of their accuracy as would TIF subjects, but little difference between the two conditions was found. The mean accuracy rating for the AIF condition was 2.3 while that for TIF was 2.4. Mean confidence ratings for AIF and TIF subjects were 3.7 and 3.6 respectively. Of those subjects who rated their accuracy in test as 3 or above (fairly accurate, accurate and very accurate) all four in the AIF condition were sure or very sure that they were correct, only two of the three in the TIF condition were sure or very sure of their judgement. These confident subjects were not noticeable for their accurate test scores. The test error for the four in the AIF group rank 3rd, 5th, 6th and 10th of the 10 scores while those in the TIF group rank 1st and 7th. It would seem that only one subject from each condition can claim to be both accurate, an accurate judge, and confident.

Table 73 Analysis of VE means for practice, test and retest.

Source	DF	SS	MS	F	P
Between					
1) Feedback	1	80.76	80.76	2.24	NS
Ss within groups	18	648.10	36.01		
Within					
2) Stage	2	384.18	192.09	5.57	**
1 x 2	2	286.58	143.29	4.15	*
s x Ss x groups	36	1242.23	34.51		

Discussion

The absolute error scores for the two conditions in this experiment indicate that there is no difference in accuracy between AIF and TIF trained subjects when they are tested immediately after practice. However, after a short delay TIF trained subjects are slightly more accurate than AIF subjects.

Constant error scores are not easy to interpret as large baseline differences in the direction of error were found. This may mean that the sample in this experiment included people who overestimated time intervals as well as those who underestimated, while previous experiments involved mainly those who underestimated. However, it may be that the secondary task affected some subjects by making them overestimate a time interval which they would normally have underestimated.

Although the large baseline variations were unexpected they do relate strongly to the direction of errors made by subjects in test and retest. Subjects trained with AIF tended to err in test in the direction in which they erred in baseline, while those trained with TIF erred in the direction opposite to that of their baseline.

When they are learning the task TIF subjects have to alter the time taken to move on a given trial depending on the feedback from the previous trials. They show a predictable learning curve over practice. AIF subjects, on the other hand, learn the relationship between the feedback and the timed movement over practice, but they do not alter their plans for the movement on the basis of previous feedback as TIF subjects do. Thus, when the feedback is removed the AIF subjects err in the direction of their original error, whereas TIF subjects, who have learned to correct that original error, tend to err in the opposite direction. The difference between the variable error scores in practice in the two conditions supports the view that AIF subjects are cued by the visual feedback, while the TIF subjects make large errors at the beginning of practice and small ones at the end, and they tend to bracket the target while learning.

The concurrent visual feedback provided in this experiment is not "action feedback" as Miller (1953) defined it, as learning does occur. However, it is a performance cue during practice, and it seems to lead to a memory trace which decays more rapidly than that available after terminal feedback training. The differences in direction of error in test are consistent with the view that the visual feedback is a performance cue, and that it prevents the subjects from knowing the direction of their original error. However, the finding that the size of the test error does not differ between the two feedback groups indicates that for this task visual concurrent feedback does not lead to inaccuracy in test as it does in the bar pressing task.

A further difference between this task and the bar pressing one is that in timing a movement subjects do not seem to use response-produced feedback to estimate their accuracy in test, and they report no subjective changes in the task when the feedback cue is removed. Visual feedback is used to control practice, and to learn the task, but subjects are not dependent on it. The nature of the feedback allows them to learn the task differently, but it does not appear to be involved in the detection of error, or in a perceptual trace built up over training.

5.5 Time estimation: the effects of AIF during training, and possible causes for the differences between this and a bar-pressing task.

When a continuous visual cue is used to teach subjects to make a movement in a given time and then removed, performance does not deteriorate immediately, and is no worse than that of subjects trained with terminal knowledge of results. After a short interval those subjects trained with AIF make more errors than those trained with TIF.

The direction of error for the two conditions differs in both test and retest. AIF subjects tend to err in the direction of their baseline error, while TIF subjects either err in the opposite direction or bracket the target. When an attempt to produce a movement in the correct time is followed by feedback indicating a large over or under estimation, there is a tendency for subjects to correct this error, consciously trying to improve performance, and as a result they err in the opposite direction. Subjects for whom a concurrent visual cue is present to guide the movement are not subject to so extreme a change in their performance, but may depend on the visual cue to control the end of the movement and eliminate error. So, in test they err in the direction of their original error, i.e. towards what they had erroneously believed to be the correct time. This can only be the case if subjects have some internal model of the correct time for the movement before they begin to learn the task. When the target is not specified, or is specified in terms which are not very meaningful, the difference in direction of test error, relative to baseline error, would not be found.

This explanation is undermined somewhat by the learning curve produced by AIF subjects during practice. When a visual cue is present it should not be necessary for subjects to make large errors at the beginning of practice and then become more accurate. This pattern was found in all the time learning experiments, whether a counting strategy was allowed or not, so may be due to subjects' lack of familiarity with such a task. Even though it was clearly explained some subjects found it difficult to understand that the visual cue represented time and moved at a steady rate across the screen, so they were unable to utilise the information with any great accuracy until after a few practice trials.

It was suggested earlier that if timing were kinaesthetically mediated then subjects who attempted to learn the feel of the task, rather than using the visual cue or counting would be more accurate in test. This suggestion was not substantiated, although it is not clear whether this is due to the relative unimportance of kinaesthesis in timing or to the unreliability of subjects' categories. There appears to be no accurate way in which to assess subjects' strategies in learning such a task. An attempt was made in one experiment to instruct subjects to use a strategy but it was a complete failure as those told to count while they learned the movement reported afterwards that they had 'watched the dots' or 'tried to learn what it felt like'. Those subjects who had been instructed to use the dots to help them build up a smooth feel for the movement reported after test that they had counted. Given such inconsistency of category the experiment was abandoned, but the failure of subjects to obey strategy instructions indicates how difficult the strategy problem is.

The use of counting during training was ruled out by the introduction of a secondary shadowing task which did not make subjects perform less accurately during practice. This indicates that the two tasks together did not overload subjects' limited capacity. As subjects trained with terminal feedback made approximately the same errors whether the secondary task was present or not, the situation cannot have been too difficult.

For both AIF and TIF trained subjects the error in test is greater when they are performing a secondary task than when they are not. The removal of counting as a method of learning the task appears to affect accuracy in test. This suggests that although verbal strategies may not be of importance in the timing of well learned tasks (Michon 1967) they are of considerable importance in the acquisition of such a task. It is possible that all subjects tried to use a verbal cueing system of some kind, at least in the early stages of training, so that the type of feedback available was not important for the acquisition of the task, and when counting was removed AIF subjects used the visual cue in the expected way and performed more accurately while it was present.

When counting is prevented AIF training gives more accurate practice and less accurate retest performance than TIF training. The accuracy in practice is due to subjects using the visual cue to control the end of the movement, while the inaccuracy of retest performance indicates that a memory trace of some kind is not as resistent to decay as it is with TIF training. Following Adams (1971) we could assign this decay to the perceptual trace, because one of the expected sensory consequences no longer occurs, or to the memory trace, implying that those who use vision to end a movement accurately do not have the movement programmed in advance.

A similar analysis could be made within a schema position such as that of Pew (1974) or Schmidt (1975).

If a movement is long enough to enable the subject to correct it during its execution based on error detection via a sensory feedback loop, a change in feedback from that which was expected could have serious consequences and could be expected to be noticed by the subject as unusual. This is the case with the bar pressing situation. However, subjects do not report anomalies in the feel of the task (kinaesthetic feedback) when the visual cue is removed- if the task is to move in a given time. This task would appear to be one in which vision does not exert dominance over other types of controlling feedback, and this is due, at least in part, to counting and other verbal strategies. However, when such strategies are not available the learned movement decays faster after AIF but there is no evidence that subjects perceive any difference in the task. This seems to be evidence against a 'perceptual trace' explanation of the control and assessment of movement, at least in the strong form proposed by Adams (1971). The removal of a strong feedback cue should lead to both objective and subjective error if it has been used to form a perceptual trace, and this is not found.

As the movements involved in the time learning experiments were slow gradual ones it is not possible to distinguish between feedback and central control of terminal accuracy when the movement has been learned. The studies of Ells (1969) and Klein and Posner (1974) have suggested that attention is given to the control of such a movement, so that feedback can be used to effect changes in on-going control. However, the differences in performance in bar pressing and time learning tasks indicate that the visual system is not involved in the same sort of way in both tasks. It may be that vision is not relevant to the production of a timed movement, except in so far as the guiding role of the feedback cue prevents subjects from making active choices about their movement, so that kinaesthetic feedback is used to code movement and this decays over a few minutes when stored in memory.

Chapter 6

The effects of visual AIF on the learning and retention of a displacement task with 1:1 gain on the feedback display.

6.1 Experiment 9 — The effects of visual AIF on the learning and retention of a displacement task with 1:1 gain on the feedback display.

Introduction

Method

Subjects

Apparatus

Procedure

Instructions to subjects

Results

Absolute error

Constant error

Variable error

Practice speed

Subjective error estimates

6.2 Discussion

Introduction

Visual feedback which appears while the response is being performed and which is thus available for accurate control of the response, causes subjects in a bar-pressing task to overestimate the required pressure when the feedback is removed. For a time estimation task this is not found, although when counting is prevented subjects trained with concurrent visual feedback are slightly more accurate in practice and less so in retest than those given terminal visual feedback. It has been suggested that the differences found are due, at least in part, to the use of a magnified display and a small actual movement in the bar pressing studies. As Fox and Levy (1969) have suggested, a task in which the movement and the display were of the same size might not give rise to the findings of visual dominance.

Accuracy in practice has also been considered as an important variable, although as would be expected from Fitts' Law it is not always easy to detach accuracy from speed of responding. However, the problem of accuracy remains. In learning to estimate a time AIF trained subjects show learning during practice and are not upset by the removal of the visual cue, while with bar-pressing practice is very accurate but performance is disrupted by the removal of the cue. If subjects need to make and correct errors before they can arrive at a modal value for the correct response then any procedure which leads to accuracy in practice may be disadvantageous. However, as Holding and Macrae (1964) have shown that movement to a stop is accurately retained when the stop is removed, concurrent visual feedback may not work in this way.

Using a displacement task (movement amplitude), with 1:1 gain on the visual display, this experiment compares retention after training with AIF, TIF, and with a stop in position. In addition, some subjects were trained with visual feedback, either terminal or concurrent, as well as the stop, in an attempt to parcel out the differences caused by accuracy in practice and attending to the visual cue.

It is hypothesized that subjects given visual AIF in training, with or without a stop at the target position, will perform less accurately in test and retest than will those who are trained with TIF or with a stop in the track. Subjects asked to estimate the movement without being given any feedback should become more consistent but not more accurate (Seashore and Bavelas 1941), and should remain less accurate than all other subjects, even those given AIF in practice.

Method

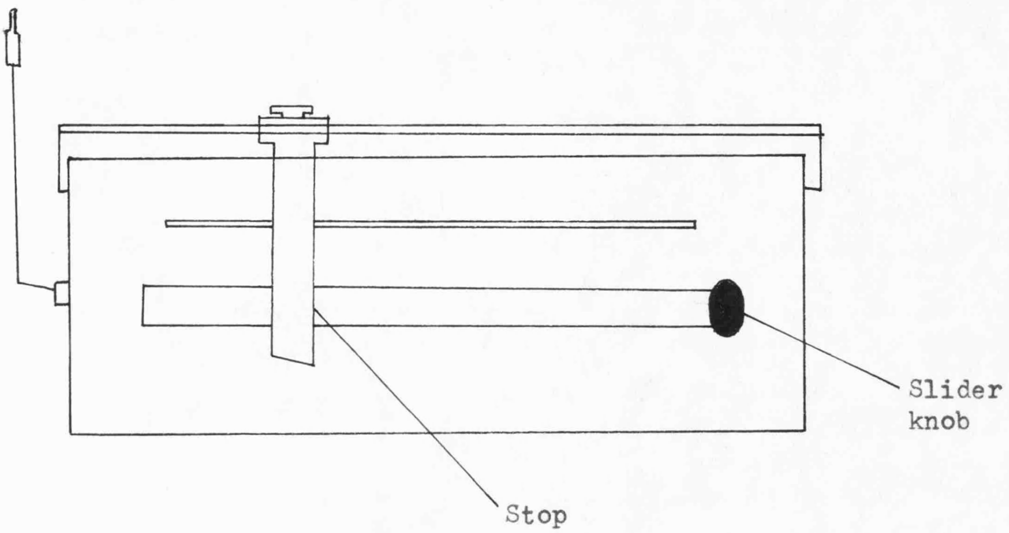
Subjects

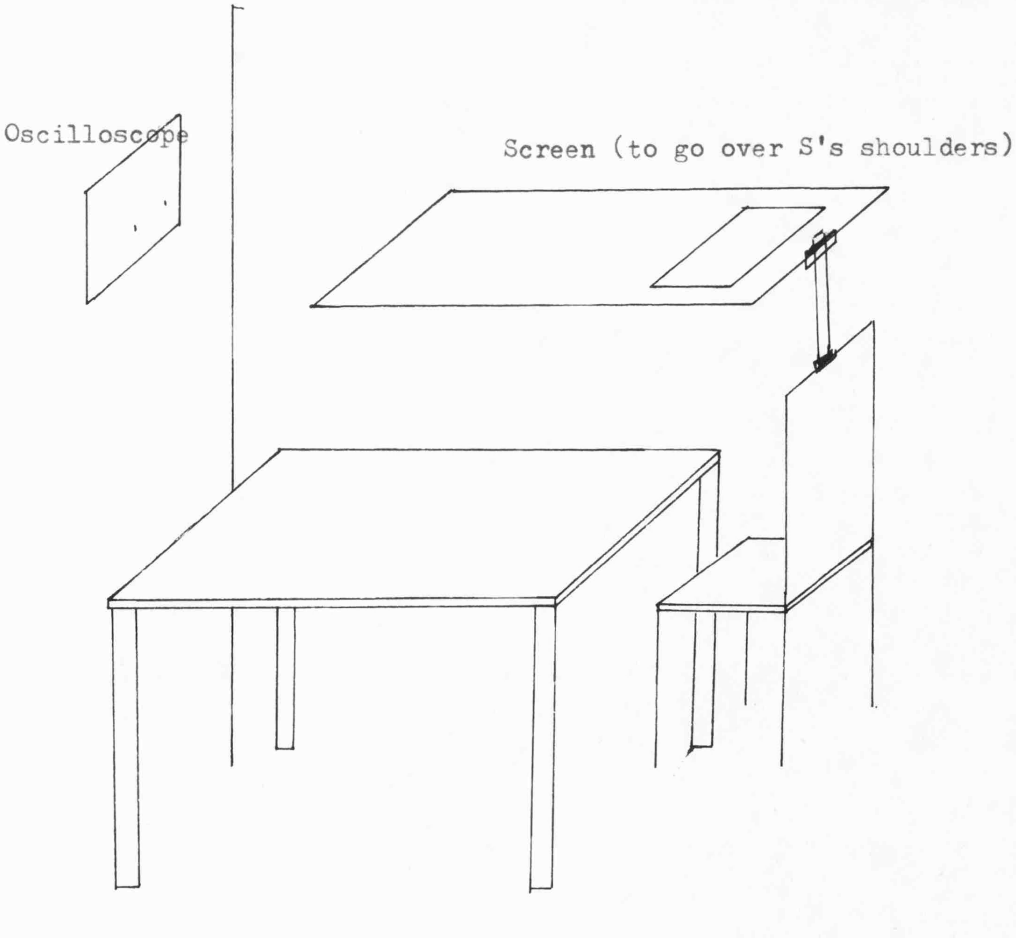
Subjects were sixty undergraduate and postgraduate students at the University of Leicester. There were equal numbers of males and females and ages ranged from 18 to 25 years with a median of 20 years. All subjects were right handed.

Apparatus

The equipment was basically a slider switch with a track 21 cms long and a round handle 2 cms in diameter, the whole set in a wooden box 17 cms wide, 35.5 cms long, and 3.5 cms high. A centimetre scale was fixed beside the track and a mechanical stop, mounted on a rod at the back of the box on which it could run freely, could be screwed into place anywhere on the track. (see diagram, Figure 24).

Figure 24. Apparatus and layout diagram for the lateral displacement task in Experiment 9.





As the switch was moved the voltage output from the batteries altered in proportion to the distance moved and this output was fed into a PDP Lab8E computer using its analogue-digital converter.

The computer was programmed to produce two marks, 6 mms high and 12 cms apart on the oscilloscope screen. These marks were on the right of the screen and approximately 11 cms of display remained available, so that more than ninety per cent error in overshoot could be displayed.

A screen which was fastened to the back of the test chair went over the subject's head and was held by a clamp just above his/her shoulders so that no movement of the hand or arm could be seen (see diagram, Figure 24). All subjects wore industrial ear defenders which cut out noise from the slider but did not remove the noise from the teletype which signalled the end of practice, as in previous experiments.

For AIF conditions a line began to appear on the screen when the subject began a movement, this line moved at the same speed as the switch handle and stopped when the knob no longer moved. Both line and switch moved from right to left. For terminal feedback the line appeared after the movement ended.

Procedure

There were six conditions, three with the stop in place and three without. The three conditions with and without the stop were: no visual feedback (NVF), continuous visual feedback (AIF), and terminal visual feedback (TIF). Subjects were randomly assigned to one of these conditions with equal numbers of males and females in each group. There were 10 subjects per condition.

All subjects performed 35 trials, for the feedback conditions these consisted of 30 practice and 5 test trials. The inter-trial interval for all conditions was 5 seconds and in the four visual feedback conditions the feedback remained on the screen for 1 sec after the movement was completed. At the removal of this feedback the target marks also disappeared from the screen and their reappearance was the cue for the next movement. Subjects removed their hands from the knob when they had finished a movement and the experimenter returned it to the starting point.

After test all subjects were required to estimate the average size and direction of their errors on the test trials.

Instructions to Subjects: No stop conditions.

a) NVF

Subjects in this condition received no information about their accuracy in the task and performed 35 trials. They were instructed:

"Your task is to move this knob 12 cms to the left. Move it the distance which you think is 12 cms then remove your hand. The knob will be returned to the starting position. When the two marks on the screen reappear move again. Repeat this until you are told to stop".

b) AIF

Subjects received AIF in the form of a moving line which remained on the screen for 1 sec after the end of the movement. There were 30 practice trials and 5 test trials followed by a subjective rating of error. Subjects were instructed:

"Your task is to learn to move this knob 12 cms to the left. As you move a line will appear on the screen beginning at the mark on the right. This line will grow towards the second mark at the same speed as you move the knob, and when it reaches the second mark you will have moved the knob 12 cms. Take your hand off when you have finished the movement. I will return the knob to the starting position, wait for the two marks to reappear and try again.

When you have practiced this for some time the teletype will make a noise * and the line will no longer appear. You have then to continue to move the knob 12 cms, as accurately as possible. Remember, the line is there to help you learn and you will eventually be tested without it".

c) TIF

Subjects in this condition received terminal visual feedback immediately they had finished a movement. This was in the form of a line which extended from the mark on the right of the screen towards the second mark. Subjects were instructed:

"Your task is to learn to move this knob 12 cms to the left. I want you to move it what you think is 12 cms then take your hand off the knob. A line will appear on the screen extending from the mark on the right towards the other mark. If it touches the second mark you have moved the knob 12 cms, if it goes past the second mark you have moved more than 12 cms and if it does not reach the mark you have not moved far enough.

When you remove your hand I will move the knob back to the beginning. When the two marks reappear you can make another estimation. This will continue for some time until the teletype makes a noise, then the line will no longer appear, and you have to continue to make 12 cm movements, as accurately as possible. Remember, the line is there to help you learn the correct distance and you will eventually be tested without it."

Stop Conditions

In these conditions a stop was placed in the track, 12 cms from the beginning. Subjects had 30 practice trials with the stop in place, in test the stop was removed. Instructions to subjects differ slightly from those above as it was important to direct visual feedback groups to both cues, the feedback and the stop.

a) NVF

Instructions: "Your task is to learn to move this knob 12 cms to the left. To help you do so there is a stop in the track exactly 12 cms from the start. You are to move the knob to this stop, remove your hand and wait for the two marks on the screen to re-appear. I will return the knob to the start. When the marks re-appear on the screen you may repeat the movement. After you have practised in this way for some time the teletype will make a noise and I will remove the stop, you have to continue to move the knob 12 cms as accurately as possible. Remember, the stop is there to help you learn the correct distance, and it will be taken away later.

b) AIF

"Your task is to learn to move this knob 12 cms to the left. To help you do this there is a stop in the track 12 cms from the start,** in addition as you move the knob a line will grow from the mark on the right towards the second mark at the same speed as you move. When it reaches the second mark you will have moved the correct distance". Then as the no stop condition until *

* "I will remove the stop, the line will no longer appear and you have to continue making movements of 12 cms as accurately as possible. Remember, the stop and the line are both cues to help you learn and you will eventually be tested without them".

c) TIF

As AIF stop condition until **

** "In addition, when you have finished making the movement a line will appear on the screen, extending from the first mark to the second one. This also means that you have moved the knob 12 cms" Then as AIF stop condition to end of instructions.

Results

Each subject provided 30 practice and 5 test scores (percentage error). For the test scores absolute, constant and variable error means were calculated. Practice errors were averaged in five trial blocks for some groups (AE), so that a learning curve could be shown, and average speed of practice was also calculated for each subject. All subjects provided subjective estimates of size and direction of error in test which was analysed chiefly in terms of direction, especially with relation to the actual direction of error.

A) Absolute Error

The mean absolute test error scores for the six conditions (Table 74) indicate that the group which received no information of any sort about error in practice performed worse than any other condition. This was confirmed by a one way ANOVA on the test scores, which was significant (Table 74) and a post hoc Tukey test which indicated that the no training condition had higher errors than all other conditions ($p<0.01$).

As the control group results were very variable differences between the experimental conditions were examined using a one way ANOVA on these 5 results. This was also significant. A Scheffé

Table 74 Mean absolute error in test after five conditions of practice and one no-practice control, and analysis of these means.

	NIF No stop	NIF Stop	TIF No stop	TIF Stop	AIF No stop	AIF Stop
Mean	28.35	8.12	6.78	7.58	11.37	13.64
S.D.	19.41	3.47	3.98	2.88	3.37	6.48
Range	10.71- 55.99	4.27- 14.58	2.59- 15.06	3.38 12.51	5.79- 16.22	5.94- 24.22

Analysis: 6 conditions: 5 experimental, 1 control.

Source	DF	SS	MS	F	p
Between	5	3296.77	659.35	8.47	**
Within	54	4204.71	77.86		
Total	59	7501.48			

Analysis: 5 experimental conditions

Source	DF	SS	MS	F	p
Between		335.75	83.84	4.63	**
Within	45	814.13	18.09		
Total	49	1149.88			

contrast test showed that the two AIF conditions differed from the other three conditions ($p<0.05$). AIF subjects were less accurate in test than those trained with TIF or with a stop only.

Mean error scores for 5 trial blocks during practice were calculated for the three no stop conditions (i.e. those in which error was possible). (Figure 25). It can be seen that in this task AIF subjects were able to use the cue to give error free performance during test (about 1% error), while the TIF subjects, although they improve after the first few trials, are not so accurate by the end of practice. Subjects with no feedback at all appear to deteriorate over practice but a Wilcoxon matched pairs signed ranks test on the mean error scores for the first and last 5 practice trials gave $T = 16$ ($N = 10$) which is not significant.

B) Constant Error

Mean constant error scores for the 6 groups were calculated (see Table 75) and analysed using a one way analysis of variance. This was not significant.

Within each condition some subjects overestimated and some underestimated the target. Even the no feedback condition, which seems to be different from the others (see Table 75), is not, as in this condition some subjects overshot by as much as 56% while others undershot by up to 33%. No preferred direction was found for any type of training procedure.

However, there were large difference in the ranges of error scores in the six conditions. The majority of the test scores in the two TIF conditions and the NIF stop condition were between the smallest positive and the smallest negative error score in the no-practice control condition. This was confirmed by the use of

Figure 25 Percentage AE over practice: No stop conditions, AIF, TIF and NIF.

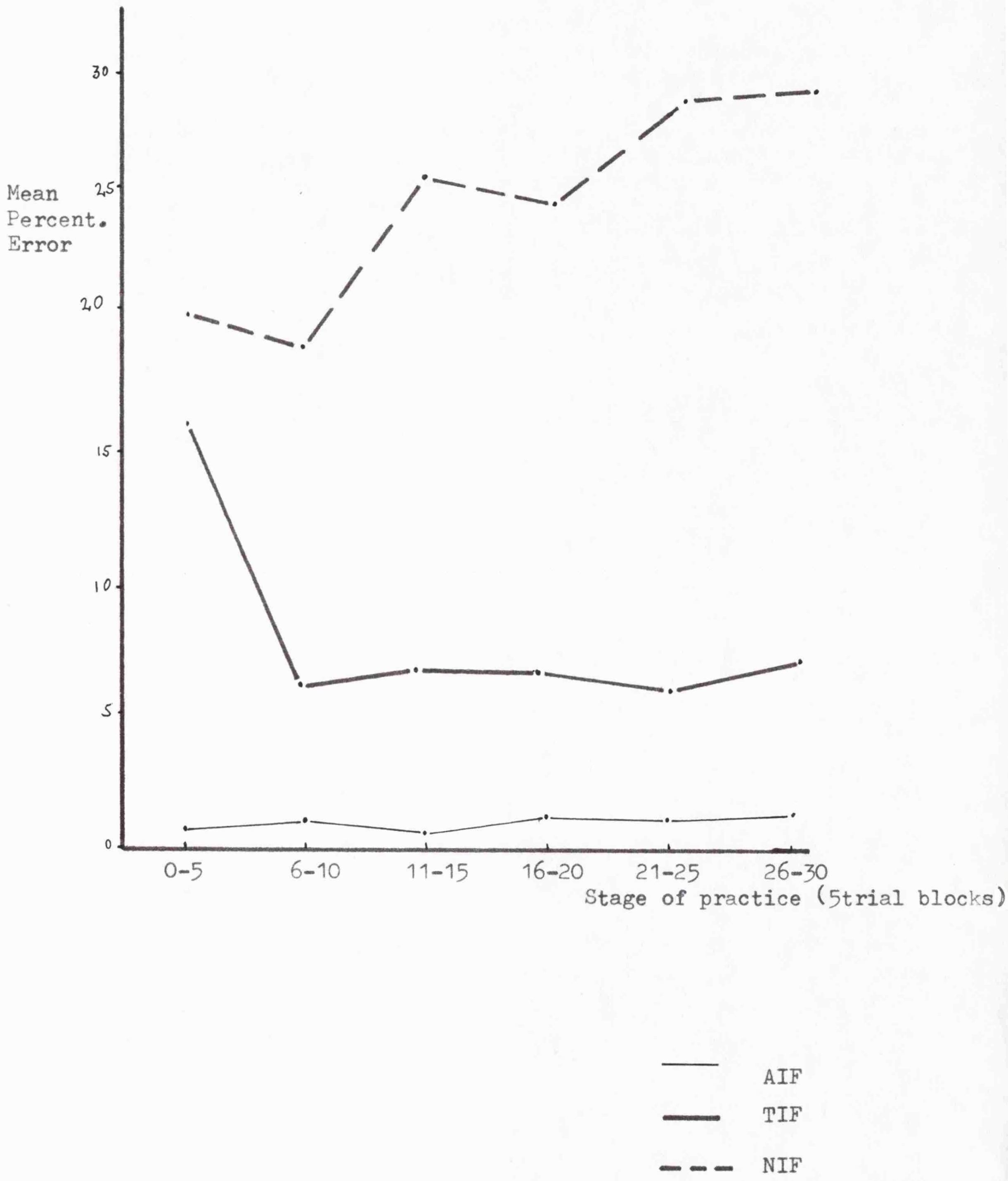


Table 75 — Mean constant error in test after five conditions of practice, and one no-practice control, and analysis of these means.

	NIF No stop	NIF Stop	TIF No stop	TIF Stop	AIF No stop	AIF Stop
Mean	16.14	1.55	0.40	2.31	-1.91	-3.61
S.D.	30.95	8.01	6.65	6.31	9.92	15.27
Range	-32.87- 55.99	-13.69- 12.90	-11.27- 9.39	-6.55- 12.51	-16.22- 11.58	-20.75- 24.22

Analysis: 6 conditions

Source	DF	SS	MS	F	P
Between	5	2482.20	496.44	2.07	NS
Within	54	12979.20	240.35		
Total	59	15461.40			

the Moses test of extreme reactions (Siegel 1956) which showed that the no practice control scores were more extreme than the TIF stop scores ($p = 0.009$), the NIF stop scores ($p = 0.03$) and slightly more extreme than the TIF no stop scores ($p = 0.063$), but they were not more extreme than those of the AIF conditions ($p > 0.10$ in both cases).

C) Variable Error

Variable error test scores were also analysed using a one way ANOVA and differences between the conditions were not significant (see Table 76). The different types of practice did not cause subjects to produce more consistent responses than no practice at all. This suggests that moving the slider 30 times causes subjects to set up a model of the correct response which they reproduce fairly consistently, even though they may not have a correct model.

Practice Speed.

Average speed of movement during practice for each subject was calculated in cms per second (Table 77). A one way ANOVA was significant. A Scheffé contrast test indicated that the two AIF conditions were slower than all other conditions ($p<0.05$).

Extremes of speed were found. One subject in the AIF condition without the stop had an average speed over 30 practice trials of 9.67 cms/sec., that is, he took approximately 1.3 secs to make a movement of 12 cms. The fastest subject was in the TIF without stop condition and in this case the average speed was 81.98 cms/sec, almost 10 times as fast as the slowest subject. However, only two of the 60 subjects practised at average speeds greater than 70 cms/sec and only two were slower than 20 cms/sec. so that in general time over the 12 cm target length varied from 170 to 600 cms.

Table 76

Mean VE scores in test after five conditions of practice, and one no-practice control, and analysis of these means.

	NIF No Stop	NIF Stop	TIF No Stop	TIF Stop	AIF No Stop	AIF Stop
Mean	7.35	4.97	4.89	5.98	7.88	6.02
S.D.	2.39	2.47	2.79	3.11	4.74	2.89
Range	3.86-11.64	1.30-9.31	2.69-12.27	1.67-12.25	2.94-17.13	2.15-12.84

Analysis: 6 conditions

Source	DF	SS	MS	F	P
Between	5	74.02	14.80	1.48	NS
Within	54	541.08	10.02		
Total	59	615.10			

Table 77 Average Practice speed (cms/sec) for 6 conditions of practice, and results of analysis of variance.

	NVF No Stop	NVF Stop	TIF No Stop	TIF Stop	AIF No Stop	AIF Stop
Mean	41.31	46.51	49.50	43.64	29.26	31.99
S.D.	14.34	17.85	13.84	13.94	10.42	9.73
Range	21.92 -67.47	22.02-70.49	31.71-81.98	23.6-68.69	9.67-38.77	21.5-50.7

Analysis: 6 conditions

Source	DF	SS	MS	F	P
Between	5	3264.14	652.83	3.519	*
Within	54	10018.90	185.53		
Total	59	13283.04			

Individual differences within conditions were quite large, but in general subjects given AIF during training took a longer time to make the movement than did other subjects. However, within the groups there was little correlation between speed of practice and accuracy. In only one group, the TIF without stop condition, was there a significant negative correlation between error in test and speed of practice ($r = -0.64$ $p < 0.05$). In both AIF conditions the correlation between test error and practice speed was very small (AIF stop $r = -0.09$, AIF no stop $r = 0.28$).

Subjective Error Estimates

All subjects were asked to estimate the size of their error in the 5 test trials (in per cent of the correct distance) and to say whether this was an overshoot or an under shoot. Three subjects said that they didn't know and refused to estimate, two of these were in the control group, the other members of which made consistently large errors, showing little variation, except in direction. There was no difference in size of error estimate in the 5 experimental groups, when direction was not considered. However, when direction of estimated error is included a Kruskal Wallis analysis of variance on the 5 experimental conditions gave $H = 9.68$ (DF 4, $p < 0.05$), which is significant. Subsequent Mann Whitney 'U' tests showed that the AIF no stop condition, in which there were 8 negative estimations out of 9, differed from both TIF groups and the stop only group (TIF stop $U = 17.5$ (9,9); TIF no stop $U = 18$ (9,9); Stop only $U = 21$ (9, 10), $p < 0.05$ in all cases). The AIF stop condition, which had 7 out of 9 negative estimations did not differ significantly from the TIF stop condition ($U = 24$ (9,9).

As so many of the AIF subjects reported that they underestimated the target during test, it seemed that there might be a directional bias in subjective error due to the continuous visual cue, as there is with bar pressing studies. The frequency of occurrence of both over and under estimations for both types of error is summarised in Table 78.

Table 78 Frequency of Occurrence of over and under subjective and estimations and their accuracy.

	Direction of Error:		
	Under	Over	Total
AIF	15	3	18
TIF + NIF Stop	7	21	28
Total	22	24	46

	Accuracy of subjective directior		
	Correct	Incorrect	Total
AIF	7	11	18
TIF + NIF Stop	21	7	28
Total	28	18	46

AIF trained subjects were compared with TIF and NIF + stop trained subjects for frequency of occurrence of over and under estimations using a chi^2 test, which was significant ($X^2 = 12.70$ $p<0.01$). A further chi^2 test on the occurrence of correct or incorrect subjective estimates of direction of error was also significant ($X^2 = 4.58$ $p<0.05$). Subjects trained with AIF are more likely to estimate their test performance as an undershoot than are other subjects, and are less likely to be correct in their estimate. AIF subjects who overshot on test never recognised that they had done so, while TIF and stop trained subjects always recognised overshoots. The actual direction of error is similar for all conditions.

6.2 Discussion

The task used in this experiment was similar in some respects to that used by Fox & Levy (1969), in that the subject was required to learn to make a movement of a given amplitude with or without continuous visual feedback. However, the results of this study are not in agreement with those of Fox and Levy. Subjects who received visual AIF during training were less accurate in test than those who did not. This effect is found even when a stop is present in the track at the target position so that it is not actually necessary for subjects to use the feedback in order to make the movement accurately. There were no differences in the direction of test error following different types of training although AIF subjects underestimated their movement distance in test when questioned after the test trials.

The important factor with AIF is not that subjects make accurate practice trials and so never experience error. Those subjects who learned to move to a stop were quite accurate in their movements in test and they did not have experience of error in practice. However, it is still not possible to disentangle the speed and accuracy of AIF practice. When subjects watch a visual display they move more slowly and are more accurate. It is more likely that the importance of the visual cue is that it enables subjects to alter a movement during its execution and requires attention. The terminal aiming section of the movement is under feedback control and this is remaining so over practice. The subject who is trained with continuous visual feedback but no stop in the track takes longer to make a practice trial than a TIF trained subject because more decisions are made and more accuracy is obtained. This feedback control of the end of the movement is not delegated to kinaesthesis over the practice time used in this study.

As performance in the AIF condition with a stop in the track was very similar to that without the stop, i.e. that in which decisions about terminal accuracy mattered, these speculations about the role of visual feedback may be unnecessary as explanations of the phenomena of poorer retention in test and estimations of error as under shooting the target. Subjects attend to the visual information whether it is necessary to do so or not, and it may be the presence of what is in essence a distracting display, rather than its relationship to the processes of producing responses which leads to poor retention of the task.

Subjects given an AIF visual display during training were more likely than those trained by TIF to report that their error was an undershoot. This difference indicates that a continuous visual cue in practice affects the evaluation of response produced feedback. However, it is not clear whether this is due to the dependence on feedback for response execution rather than the subjective evaluation of performance. If the effect of the removal of the visual cue were to lower subjects' confidence because confirmation of accuracy was no longer available, error estimates would be expected to be wrong but it would not be expected that most subjects would consider that they had erred in a particular direction, that is, that their test responses were undershoots.

The finding that AIF subjects tend to report an underestimation is support for the view that without the visual feedback kinaesthetic information was interpreted as meaning less movement, i.e. a small intersensory or visual dominance effect is operating such that during practice, kinaesthetic cues, which are less informative than visual ones, are not attended to except as part of the total response feedback in conjunction with the visual information. When the visual cue is removed the kinaesthetic feedback gives less information than the subjects have been accustomed to and subjects feel that they have underestimated the target. Again, this is slight evidence for a view of two processes in movement control, one central and organisational, perhaps a motor programme, and the other peripheral and error detecting. When visual feedback is removed it would appear that subjects trained in this way have a less accurate model, schema, or motor programme, than those trained with TIF and that the error detection mechanisms cannot operate accurately because the attention given to vision, or to the vision-kinaesthesis combined response-produced feedback, so that the kinaesthetic feedback alone does not give enough information.

The results of Fox and Levy (1969) which have indicated that concurrent visual feedback does not have an effect different from that of terminal feedback differ from those reported here and this may be because their procedure differed from the present one in two ways. In Fox and Levy's study the subject watched his/her hand directly, rather than seeing the results of the movement transformed on a display and the movement did not start from the same position on each trial so that distance and place learning were not confused.

It is not clear why subjects should be less accurate in test after training in which they had a visual display giving AIF than they are when visual feedback and movement of the hand were perceived directly, i.e. visual feedback was also kinaesthetic in the sense in which Gibson (1966) uses the word because it gave information about movement of the body. Visual information given by varying the length of a line on a screen does not obviously correspond to kinaesthetic feedback about the movement in the same way as watching one's hand move does. Subjects have considerable experience of integrating concurrent streams of feedback when they move, and feel and see the movement. It may be that a new congruence between movement, kinaesthesis, and vision has to be learned in the experimental situation which prevents direct sight of the hand moving, even though the visual display shows the amount of displacement exactly as it occurs. This point is worth noting, both for training procedures in which AIF is given by display during training, and for research into the effects increased and decreased amounts of feedback on learning and retention of discrete movements.

The mingling of distance and location cues in this study may have made it more likely that kinaesthetic cues would be poorly retained. Location cues are interfered with by an intervening task while distance cues decay over time (Laabs 1973, Keele and Ells 1972). It has been suggested (Laabs 1973) that location and distance cues are differentially coded - location is coded centrally and is in need of rehearsal, while distance is kinaesthetically mediated and decays. Posner (1967) found different memory codes for visual and kinaesthetic information and suggested that vision was central while kinaesthesis was peripheral and decayed. In general, it would appear that location may be mediated by visual cues and therefore, if subjects were using the visual feedback to learn the location of the end point rather than the distance moved poorer performance could be expected when the visual cue was removed and only distance cues were available. However, it is not clear that the findings of short term motor memory studies in which very few trials with the target distance or position are given, can be applied to training over extended practice during which the organisation of the movement is improved as well as the recognition of the correctness of the response-produced feedback.

Chapter 7

General Discussion

7.1 Summary of experimental findings

The results of these studies allow some conclusions to be drawn about the effect of a continuous visual feedback cue on learning and retention of simple skilled tasks, and raise questions regarding theoretical problems such as visual dominance of other sensory input, control processes in movement, and the role of awareness in the skilled and unskilled performer.

In summary, the results of experiments in concurrent visual feedback with a bar pressing task support those of Annett (1959). Subjects trained with a concurrent visual cue perform less accurately in test than those given terminal feedback during training. Even after four hundred practice trials subjects trained with AIF tend to overestimate the target pressure, while those trained with TIF bracket it.

The direction of error found in test performance after AIF training in a bar pressing task supports Annett's (1970) suggestion that an intersensory effect is operating. This is interpreted in the light of other studies of visual dominance of sensory input, and can be seen as evidence for visual capture in the long term as well as in the short term learning situation.

When display/movement gain is 1:1 visual and kinaesthetic feedback are congruent, but there is again inaccuracy when the visual feedback is removed. Visual information may dominate other inputs even when congruent, although it is likely that in this case vision was important in the learning situation as part of the task was position learning.

A concurrent visual cue does not work in the same way as guidance, as a few guidance trials early in learning can be helpful

(Holding 1965), while a few concurrent visual feedback trials with a bar pressing task lead to very large errors of overestimation. It seems that over a longer period subjects become capable of producing a more accurate movement and of estimating it more accurately.

Production and recognition in pressure and lateral displacement tasks are affected by a visual cue which results in subjects performing more slowly, more accurately, and not programming their movement completely at the beginning. Accuracy of practice alone however is not an important factor, rather it is subjects' willingness to allow the movement to be controlled by external factors which prevents the setting up of an accurate programme. Subjects are distracted by the visual cue even when it is irrelevant to their performance in practice and they could learn the task without attending to it at all.

Results from time learning studies do not fit this pattern. Even when the possibility of counting as a mechanism for timing has been removed, subjects were not adversely affected immediately by the removal of a visual cue with which they had been trained. It is suggested that the visual cue cannot be effective because vision has no role in timing and subjects do not use it to perform accurately in practice, as they do with the other tasks. Thus there are some types of task in which a concurrent visual cue might be a valid method of training, but they do not include position and distance learning, or pressure learning with a magnified visual display.

7.2 Visual dominance

The phenomenon of visual dominance or visual capture has been known for a long time (Gibson 1933). Visual information has a tendency to dominate that from other sensory systems when two types of information are available at the same time. (Howard and Templeton 1966). Many studies using distorting prisms have shown that subjects perceive straight edges as curved (Gibson 1933), and small objects as large (Rock and Victor 1964), and that parts of their bodies are not where they feel to be (Pick, Warren and Hay, 1969, Welch 1972). When subjects are required to react to two types of information which are presented simultaneously the visual cue is attended to even when this results in a slower reaction time (Jordan, 1972), and the other signal may be missed completely (Colavita, 1974). Posner & Klein (1974) have shown that subjects in a short term memory task are unable to ignore visual information which they know is irrelevant to the subsequent reproduction of the remembered movement. A recent review of the area by Posner, Nissen and Klein (1976), presents these findings in some length and compares theories of visual dominance. They suggest that the processing of visual information requires more attention than does processing other types of sensory information.

Visual dominance in studies of adaption to prism displacement has suggested that proprioception is recalibrated by vision (Rock and Harris 1967). However, this appears to be influenced by the locus of attention in such studies. When subjects are directed to attend to one or other of the types of input during exposure to the displacement it seems that recalibration occurs in the unattended modality (Kelso et al. 1975). On most occasions when conflicting information is presented no indication is given as to which modality should be attended to, and as vision predominates in these situations there is considerable support for the suggestion that vision normally receives more attention than other input channels.

The experiment by Welch (1972) in which subjects believed that they were looking through laterally displacing prisms at their own finger pointing at a target, showed, as would be expected, that if the experimenter placed his own finger to one side of the subject's non-visible finger adaptation took place even although the goggles worn were actually plain glass. However, even when subjects knew the finger to be that of the experimenter some adaptation took place. From their comments "many of the subjects in this group at least occasionally experienced the visible finger as their own, even although they knew better" (page 456), which suggests that visual capture is powerful in this situation. In general, it would appear that in many visual capture situations both motor commands and kinaesthetic feedback are consonant while visual information is dissonant, yet it is the visual information which is taken as representing the true situation.

That this is not always the case is shown by as elegant experiment by Easton (1976). Subjects traced a straight edge which they viewed though prisms so that it appeared curved (Gibson 1933) and the pressure which they exerted on the edge was recorded. More pressure was exerted at the beginning and end of the movement, as would be expected if the edge were curved, rather than pressure being equal all along the length of the edge, as is found when distorting prisms are not worn. In this case the visual information is acting as feed forward for the output of a curved movement, so that both motor commands and kinaesthetic and tactile feedback are relatively congruent with the distorted vision.

In tasks in which subjects are asked to respond to one of two stimuli presented together, the reaction time to a visual signal is faster than when such a signal is presented alone. Nickerson (1973) suggests that if the second stimulus is an auditory one then it arrives before the visual one and serves to alert the subject to the appearance of the visual cue. Colavita (1974), using simultaneous presentations of a light and a tone found that the tone was often not even perceived, which suggests that if an auditory signal does act as a cue for the visual one is is not actually perceived as such. Posner et al. (1976) looked at a reaction time task in which visual or auditory warning signals were presented before the target signal, which was also either visual or auditory. They found that reaction time to an auditory stimulus was not improved by the presentation of a visual warning signal although auditory warning reduced reaction time in both auditory and visual tasks, and visual warning decreased reaction time in a visual task. They interpret this as support for their proposition that visual stimuli are less likely to alert the subject than are stimuli on other modalities, so that unless attention is explicitly directed elsewhere it is advantageous to attend to vision most of the time and trust to the alerting properties of other modalities to convey information which requires a response.

When visual and kinaesthetic information are presented simultaneously effects similar to those reported by Colavita (1974) are found. Subjects do not respond as quickly as they would to the kinaesthetic cue alone, but their reaction time is similar to that found when a visual cue is presented alone (Jordan 1972). Klein and Posner (1974) presented a pattern of movement visually, kinaesthetically, or using both feedback systems. They found that subjects who were told to attend to the kinaesthetic cues so that they could reproduce the movement without vision were less able to do so than those attending to the visual cue or to the kinaesthetic cue alone.

None of these findings are concerned with well - learned movements in which direct feedback control is not apparent because the organisation of the task has improved. However, the influence of vision on other sensory channels has been shown in a range of experimental situations and the general conclusion is that if two sources of information are both relevant to the task, attention will be paid to vision, and some of the results from the experiments reported in this thesis appear to be explainable in such terms.

In the bar pressing task used in experiments 1 to 5, vision informs the subject that a large movement has taken place, while kinaesthetic cues indicate that a small movement occurred. Thus, two sensory systems provide conflicting information, and although subjects have been warned that they will be tested without visual feedback, they appear to be unable to use the kinaesthetic feedback effectively, and seem to perceive the movement as being larger than it really is. However, not only the kinaesthetic cues but also the motor command are being contradicted by the visual feedback. Thus, as this task is under feedback control at the early stages of learning, subjects feel that they have to press the bar very hard in order to reproduce the movement when the visual cue is removed. After two or five trials with the large visual display, subjects are convinced that they are making and feeling a much larger movement than is actually the case, because they pay most attention to the visual cue.

It has been suggested (Annett 1970) that large overestimations are to be expected in a task which involves a small movement and a large display gain, on the grounds that a small movement gives very little kinaesthetic information while a large display allows a considerable amount of visual information. In this case visual dominance is interpreted simply in terms of the relative informativeness of the visual cue. This means that either a decrease in the size of the visual cue or an increase in the size of the movement would lead to smaller overestimations in test. As no change was found when the visual display was halved it may be that the precise 'intersensory' effect only occurs with comparatively small increases in size from movement to display. The halving of gain with a bar pressing task provides some evidence that visual and kinaesthetic information is not simply added over any possible range of movements and display gains.

The relationship between visual and kinaesthetic feedback is further complicated by the amount of practice given on a task. Annett's (1970) results were found after ten practice trials and the results of Experiment 2 in this thesis suggest that large overestimations to be expected after a few AIF trials but that this decreases with practice.

When subjects are allowed large amounts of practice the role of feedback changes, as does the relationship between vision and other sources of information. After amounts of practice ranging from 50 to 400 trials, subjects do not make such large errors as after two or five trials, although some continue to make very considerable overestimations. Indeed, after four hundred practice trials the actual size of errors is only slightly larger than that after 50 practice trials without the distorting visual cue. However, the direction of the error remains consistent, i.e. even after extensive practice subjects have not completely overcome the distorting influence of the visual cue and still make a larger movement than is necessary. The small size of these errors suggests that over practice a change in the locus of control has taken place and the movement is no longer totally under the control of the misleading visual feedback.

When subjects are required to make a twelve centimetre movement with twelve centimetres of visual display indicating that the movement is correct, there is no discrepancy between the visual and kinaesthetic information. This is a similar situation to that in which Fox and Levy (1969) state that there is no effect on performance if a concurrent visual cue is removed. However, in the study reported here (Experiment 9) the mere presence of a visual cue during practice appears to have an effect on test performance, even if the cue was not necessary for learning the task. Subjects were less accurate than those trained without a concurrent visual cue, and they believed that they had undershot the target. Annett (1970) suggests that with movements of the order of 100 mms and 1:1 gain there should be no overshooting, and indeed this is the case. However, the extent, if not the direction of error is different for subjects trained with AIF. Even when there is no incongruity between visual and kinaesthetic information, subjects trained with AIF are less accurate than those trained by other methods.

The subjective reports of subjects trained with a continuous visual cue indicate that they evaluated the feedback from the test movement on the basis of the feedback present during training. The direction of subjective error is not related to that of the actual error but instead seems to indicate that subjects made the movement, assessed it, and on the basis of comparison with expected feedback traces, decided that the movement has been too short. This implies that whatever the actual movement distance was, the kinaesthetic feedback from it did not measure up to the expected feedback consequences. The distance moved was less than had been intended. Subjects may expect kinaesthetic feedback to give the same information as visual plus kinaesthetic feedback and they find that it does not, so even after training it is difficult to judge the accuracy of one's movements without visual feedback.

This finding suggests that visual dominance can take place even when two types of feedback are congruent, provided the two feedback systems can code different aspects of the task. Posner et al.'s (1976) finding that vision receives more attention suggests that in this situation division of attention is not efficient. If both visual and kinaesthetic coding is possible and subjects are directed to attend to the kinaesthetic information and tested without vision then those aspects of the task which allow visual coding will be at a disadvantage in the test situation.

Most of the recent work on coding in motor memory has been concerned with short term memory and kinaesthetic cues alone. However, there is some agreement that location and distance cues may be coded differently (Laabs 1973, Martenuik et al. 1972, Keele and Ells 1972, Stelmach 1974). Laabs (1973) has suggested that distance is coded kinaesthetically and decays, while location is coded centrally and can be rehearsed. No visual feedback was used in this study so it is not clear whether visual information would alter this differential coding although Stelmach (1974) has suggested that if visual information were present it might override the available kinaesthetic cues. One study which did use both visual and kinaesthetic cues was that of Posner (1967) who showed that there was little forgetting of visually coded movement, provided rehearsal was possible, while kinaesthetic information decayed over time.

If the results of Posner (1967) are combined with those from the distance and location studies it can be suggested that when both visual and kinaesthetic cues are present the visual information is used to build up the central, rehearsable trace which is related to the location of the target, while kinaesthetic cues are used to code distance. Thus, subjects trying to remember a movement distance would not be affected by the removal of a visual cue as this is not involved in coding distance, whereas in a task where both visual and kinaesthetic cues were present the visual cues would override the kinaesthetic ones and error would be expected when the visual cue was removed.

If interference from a visual cue is not expected when vision is not relevant to the coding of the movement, and distance learning depends only on kinaesthetic cues, then a distance learning task such as that used by Fox and Levy (1969) would not show a decrement in performance when the visual cue was removed. The apparent contradiction between the results in Experiment 9 and those of Fox and Levy (1969) can be resolved in terms of the type of task used and the relevance of vision to the learning and retention of that task. When both distance and location cues are available vision has a role and therefore performance is disrupted if vision is removed.

Concurrent visual feedback during training should not be detrimental to the control of movements if vision is not used to code the movement in memory. As there was no immediate decrement in performance of a timing task when visual feedback was removed, it is possible that vision is not important for the timing of movements.

It had been expected that watching a visual cue in order to learn to time a movement would be like watching a clock in order to do so, and that this would provide a strong visual cue which would distract the subject's attention from the movement itself, but this was not found to be the case. Not only were there no differences in accuracy immediately after test between those tested with AIF and those trained with TIF, but the subjective reports from the two groups were very similar. This is the only task in which subjective reports did not indicate an effect of the visual feedback. Subjects in the AIF condition did not feel that they were in difficulty when the visual cue was removed, and there were no reports of changes in the characteristics of the equipment, or of consistent underestimation of the target.

To fit the findings with a timing task into other results of visual dominance it is necessary to make the assumption that vision has no role in timing, either because kinaesthesis is used (Schmidt 1971, Adams and Creamer 1962), or because timing is centrally organised and totally independent of sensory feedback (Jones 1973). The findings of Cummings and Santa Maria (1974) provide some support for the kinaesthetic mediation of timing. Some further evidence that kinaesthesis is important in timing movements rather than in the serial organisation of output is provided by Roy and Martenuik (1974), whose subjects learned to make a one second movement or a 150 millisecond movement with considerable kinaesthetic feedback provided by a heavy flywheel. When the kinaesthetic feedback from the movement was changed the performance of the fast movement was not affected but that of the slow movement was. That is, when feedback could be used during the movement a change in kinaesthetic feedback led to a change in performance of a timing task.

If vision is not important for storing and producing a timed movement then no dominance effect will occur, and the results found in the present studies would be expected. Visual information may be used to give information about accuracy of movement in practice but it does not 'capture' the production and assessment of the movement. It is tempting to suggest that the time-learning results support a theory of kinaesthesis as the mechanism of timing, but this does not follow and some independent support for the position is still required.

The suggestion that visual AIF affects the learning and retention of some motor tasks because of the relationship between visual and kinaesthetic feedback implies that it is not the temporal and guiding nature of the AIF but the fact that it is visual which is important. This is obviously not the whole story, but experiments in which AIF is presented on another modality might clarify the issue. Previous studies have used auditory cues as an error signal, not as cues to guide the response towards the target (e.g. Smode 1958), and it is difficult to conceive of another modality which can present the target and the current position of the response simultaneously, as vision does. If the target could be specified auditorily and be approached by an auditory cue the situation would be similar to the visual one. This could be done if the loudness of a tone decreased as the subject approached the target, so that when the correct position was reached the tone was longer heard. In this way error in practice could be kept small and there would be simultaneous auditory and kinaesthetic input.

If such an auditory cue were combined with a visual AIF cue there would be three feedback channels operating simultaneously to code movement information, and it is possible that hierarchies of dominance would be found in which vision biased audition and audition biased kinaesthesis. However, if auditory feedback had no effect on the learning and retention of a movement it would be difficult to say whether this was due to the comparatively crude nature of the feedback or to the independence of the two feedback channels.

It is not very clear why visual information should require more attention so that processing is limited in other modalities and the phenomema of visual capture occur. Posner et al. (1976) conclude, on the basis of their experiments and those of a wide range of other workers, that the results "point to an account of visual dominance as a bias in the direction of the attentional mechanisms toward the visual modality" (p. 169). This does not advance the position very far. However, they do suggest that visual input is not very alerting (based on the reaction time studies mentioned earlier), so that people have to learn to direct their attention to vision. This explanation may be either an evolutionary one or an individual learning one and it is at least equally probable that other modalities, such as audition, have shorter reaction times because they have to attract attention <u>away</u> from visual input. The finding that dominance can be induced in other modalities if the subject can be persuaded to give them most attention suggests that this may be a more plausible explanation.

Vision provides a greater knowledge of spatial relationships than any other modality and it allows simultaneous, rather than successive perceptions of objects, which can be important. The rich visual environment requires analysing in considerable depth and this requires attention. If humans made a much smaller range of decisions on the basis of perceptual input then visual reaction time would be much faster, as it is for example in the frog. For the frog there is a direct link between input and output, for the human the sheer volume of information present in the visual world requires processing on many levels before decisions can be made (Arbib 1972). It is possible therefore that visual processing is the normal state of the human perceptual system, and that because vision is more informative about spatial organisation than the other senses are, we do not normally pay so much attention to the other senses..

7.3 Feedback and the acquisition of skilled movements

Information processing models of the control of movements have not always been able to account for learning. Adams (1971), Schmidt (1975) and Pew (1974) are among those who have attempted to describe how accurate movements are acquired, and they have tended to limit their models to discrete movements and have not been concerned with the complex patterns of behaviour which can make up skilled performance. This can lead to some confusion in terminology as, for example 'motor programme' can be used to refer to the patterning of a sequence of actions (Keele 1975) or to the plan for the initiation of a discrete movement (Jones 1974) and this can have considerable consequences for the ways in which the roles of feedback and programming of movement are understood. However, many of the models considered in chapter 1 have a certain amount in common, and from them a general theoretical position can be established, although this is probably restricted to discrete movements.

In response to the demands of the situation in which a movement is to be made, motor commands based on previous knowledge of similar situations lead to movement which results in some type of sensory feedback (kinaesthetic, tactile, visual or auditory cues may all be present), and usually some knowledge of the success or failure of the movement in relation to the original criteria. If the movement is fairly slow, then as it is being executed some sources of feedback, such as kinaesthesis or vision, may indicate that the outcome is not going to be the desired one, and a correction is initiated. This suggests that some idea of the feedback to be expected existed before the movement took place, and while this may be intuitively obvious for aiming movements which are visually controlled, such as reaching out to pick up a pin, it is not so obvious that we have expectations for other feedback modalities. However, the relationships between movement and visual feedback have had to be built up during sensori-motor development, and there is no reason to suppose that this has not occurred for audition and kinaesthesis as well.

During the acquisition of the movement subsequent attempts are 'error-tagged' with the information from knowledge of results so that over practice a modal value with little error becomes a strong trace and is most likely to be reproduced on a subsequent occasion. The stored pattern of muscle contractions with its associated error tag may correspond to the 'efferent copy' (von Holst 1954) in that it could operate as a central error detection system in the absence of any type of feedback (Pew 1974), however, cases of movement without afference are rare, and those of error detection without it are rarer still. If feedback operates as an error detection mechanism it is suggested that a feedback trace is built up during practice as the relationship between the expected and the actual feedback is also error tagged with information from knowledge of results. Schmidt (1975) suggests that the expected feedback is that for the correct movement, not for the movement actually chosen on each trial, thus the actual feedback from a movement will be 'tagged' and used to alter future expectancies if this is necessary.

Subjects who have learned to make a particular movement will know both what they ought to do, and what they ought to feel, see, or hear during the action. These types of knowledge may have very different roles in the control of the acquired movement, or pattern of movements, and these roles may change during the learning process. With practice, the organisation of output improves and the expected feedback becomes more accurate, but in the early stages of acquisition response-produced feedback from an on-going slow movement is more important for the control of that movement than the plan or programme which is based on the information from previous knowledge of results. Subjects do try to reproduce what the movement felt like, or what they think the correct movement should feel like given the knowledge of error in previous movements. It is at this stage that differential coding of sensory information affects the memory for the task so that the relevance of visual cues to the type of task is of considerable importance. However, when a movement is well learned, feedback control is less obvious. Subjective feelings of automaticity in the performance of well learned skills mean either that feedback is no longer attended to at all (Jones 1974) or that feedback is used to monitor for error, which rarely occurs because the programme for the movement is quite accurate, so that attention can be shared more easily with other tasks (Pew 1974).

This model is clearly conceptual rather than predictive, although any prediction made might be accurate for one type of task but not for all of them, particularly if speed of execution or complexity of serial order are important variables. There is the suggestion however, that two types of memory are involved, and that recall and recognition in motor memory depend on different types of memory code.

In verbal memory recognition tests show that subjects 'remember' more than can be shown by recall tests, but it is assumed that recall and recognition are different methods of tapping the same memory store, and that the difference is due to the extra cueing in recognition tasks - more cues enable retrieval to take place more easily. In motor memory Adams (1971) has suggested that recognition and recall reflect two types of memory store. Recognition is based on the comparison of feedback received with that expected for the movement, so that feedback from passive movement or mechanical guidance can be 'recognised' as that which should arise from a criterion movement. Recall memory involves active movement and the initiation of the correct programme. In most cases of active movement it will of course include recognition memory, unless the feedback sources are removed.

The perceptual trace or feedback expectancy for the task will only match incoming feedback which conveys the same information as the previous inputs which have gone to make up the trace. Thus, if a dominant feedback cue is removed, the programme for the movement and the expected feedback will not be congruent in that the same efferent command will produce different feedback. As error detection is a very important function of feedback early in learning, mainly because there are more errors, it would be expected that subjects would make large errors when a dominant feedback source is removed early in learning. This is what was found after a few trials with a bar-pressing task. Subjects were using response produced feedback to control the movement and they received an erroneous impression of how large the movement was because there was a large visual display.

When a continuous visual feedback cue is present over a large number of practice trials and subjects show that they are dependent on it by making errors in test, either the feedback is still important in controlling the termination of slow movements, or a dominant, attention drawing visual cue prevents the setting up of an accurate motor programme. The results from extended practice with a bar pressing task do not resolve this question. Although subjects produced quite accurate movements and a reasonably accurate motor programme may have been set up, the small errors which did occur were in the direction predicted by the use of a magnified visual display in training. Either the programme is in error or some terminal accuracy is still feedback controlled and the kinaesthetic feedback available is still influenced by the amount of visual information in the perceptual trace. However, the finding that a cue on which subjects depend does not prevent them from learning the task eventually, does imply that the effect of continuous feedback can be overcome and the expected feedback from the movement becomes similar to that which actually occurs when the visual cue is removed.

The concurrent visual cue in a bar pressing task appears to affect both recall and recognition of the correct movement. The attention given to the visual cue for terminating the movements means that the end of the movement is not pre-programmed; subjects tend to use the response-produced feedback during the production of the movement, which is slow enough to allow this, but they also use it to evaluate the movement once it is made.

Recognition of the correct movement means that subjects will know how accurate they have been in a well learned movement before they are told, that is, they use the expected feedback for the correct movement and compare the actual feedback with this. Subjective reports may differ from objective error if the two memory systems are built up differently. However, subjective error reports after the bar pressing task are difficult to interpret, although it is clear that subjects are not attempting to reproduce a 'feel' of the correct movement as they should then rate their own attempts as accurate. Subjects do three things when the visual cue is removed, a) they press harder than is required, b) they perceive the bar as stiffer, and c) they say that they have not been accurate. These

These three things are not strongly related, that is, those subjects who press hardest do not perceive the increase in stiffness as greatest, nor do they make the largest error estimation. It seems that the scaling of subjective experience is not related directly to that of behaviour. Subjects do not realise that the stiffness of the bar can be reduced by pressing less hard, and the recognition of the accuracy of the movements is generally poor, as would be expected if recognition is based on feedback traces which were dominated by visual input.

The removal of an important source of feedback leads to a lack of confidence in accuracy, even when actual performance is quite good, and the overall direction of error indicates that response-produced feedback is involved in the accurate reproduction of a learned movement. The subjective feeling that the bar has become stiffer is related to the original uninformativeness of the kinaesthetic feedback which was later swamped by the dominant visual cue.

When the task is a simple lateral displacement with no gain on the visual display the role of feedback in the acquisition of the movement is not so clear, partly because the two main sources of feedback were not incongruent and partly because a small number of practice trials were used and different results might have been found with extended practice.

The model outlined earlier described the acquisition of a movement in terms of active choices on the subject's part and the availability of terminal knowledge of results. Subjects experience error in training and so may learn to recognise it, and they build up a programme for the correct movement which they initiate and control. However, if a response-produced feedback cue guides performance, prevents error, prevents active choice of the sequence of efference commands, and distorts kinaesthetic feedback, it is not surprising that error is produced when the feedback is removed.

When movement is made to a stop subjects do not experience error and they do not choose the extent of the movement which they initiate, but when the stop is removed they perform quite accurately. During training they make very fast movements and there is considerable feedback from the stop at the end of the track which may be associated with the end of the movement when the stop is removed. In addition, subjects could move very quickly for a period of time in order to be accurate in test, i.e. they have learned how long to move for, not how far to move.

The addition of a visual feedback cue to a stop condition makes it quite clear that it is the attention given to the visual cue which causes the deficiencies in test performance. Practice trials with vision are typically slower than those without, whether the visual information is relevant or not, so subjects have time to attend to the feedback without which they cannot operate accurately. It is not the lack of experience of error which prevents subjects from learning the task well, but the presence of an attention drawing visual cue which means that they do not set up an accurate programme for the task.

Subjective reports from those trained with the visual cue for this task indicate that the change in feedback prevents the accurate assessment of the movement after it is made. Subjects over and underestimate the target position in test trials but they tend to report that they have undershot the target, that is, their assessment of the feedback from a movement is influenced by the earlier dependence on vision. Kinaesthetic feedback alone indicates a smaller movement than visual and kinaesthetic feedback for the same displacement.

In short term motor memory it has been suggested that kinaesthetic coding leads to errors of undershooting. Kantowitz (1974) found that subjects who had been given visual information could discriminate equally well between a criterion movement and under- and over-shoots. However, for kinaesthetic information, movements which were over the criterion were discriminated more accurately than those which were under the criterion, i.e. subjects had an undershooting 'set' (Pepper and Herman 1970). While it is not easy to generalise from this isolated study of short term retention to kinaesthetic coding in general, especially when large amounts of practice are involved, this finding would help to explain why there are errors in test after visual AIF in practice, when there is no discrepancy between the types of feedback available during practice. It is significant that both reports of under-shooting are subjective ones, that is, they are based on subjects' judgement of feedback from a movement rather than from the performance of the movement itself.

In active movement, even that which has been well practised, it is not easy to separate motor programme formation and the use of feedback. When a concurrent visual cue is present this prevents the formation of an adequate motor programme until after a large number of trials, and alters the way in which a test trial is carried out and assessed. As there are elements of recall and recognition in any movement produced actively by the subject it is not possible to totally separate the two. Although there are indications that recall plus recognition produces different results from recognition alone, (i.e. the execution of a movement, controlled by a motor programme and some guiding feedback, produces different error sizes to those given in the subsequent assessment of the movement), subjective reports have not been easy to deal with and are treated cautiously as a source of data.

The results from the time learning experiments do not fit with the others. This may be due to the nature of the task as vision may not be relevant to the perceptual trace for a timed movement. However, it could be that as both AIF and TIF trained subjects move in the same time the amount of attention paid to response produced feedback would be the same. If it is the attention paid to feedback in practice which leads to error in test performance, then the results might indicate that terminal feedback is as bad as continuous feedback when there is a lot of time available rather than that continuous feedback is as good as terminal because of the coding of timed movements. However, if this were the case, then fast timed movements, in which feedback could not be used, should show better retention than slow ones and this was not the case. It is not the speed of the movement which affects its retention after different types of training but the fact that it was a timed movement.

The small amounts of error found after AIF training on a timing task, and the lack of subjective effects when the cue was removed does not mean that other findings about AIF training are wrong, but rather that experimenters who use a timing task with conditions of reduced feedback should be very cautious about interpreting their results. Making a movement in a given time does not give a similar trace to making a movement of a set distance, and a feedback cue will only be important if it is relevant to the task itself. In a timing task AIF trained subjects have more experience of error and they are not so dependent on the visual cue for the control of movement, and when they estimate the accuracy of their timing, visual information is not relevant.

Over two tasks in which visual feedback was either incongruent with kinaesthetic feedback or could be used to remember the task, performance after the removal of such feedback comparatively early in learning (up to fifty practice trials), indicates that concurrent visual feedback prevents the consolidation of traces which will operate when the cue is removed. Subjects do not organise the movement, that is, they form poor motor programmes, and they do not recognise their own error, but appear to allow the distorting effects of the earlier visual feedback to control their actions and their assessments of those actions. Later in learning (after four hundred practice trials) test performance is reasonably accurate although the direction of error remains consistent with a terminal feedback control of the movement which is partly programmed. Even for a comparatively well learned task motor programming is not simply the predetermining of what movement will be carried out and what feedback will follow, as, where accuracy is concerned, subjects will use available feedback and not be operating completely in a central control mode. While subjects may be able to perform skilled activities with little or no response-produced feedback (Lashley 1917, Jones 1974), feedback is important for the acquisition and control of accurate movement, and the removal of some types of feedback is detrimental to performance. Without feedback subjects can perform but they cannot necessarily perform accurately.

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