

**THE EFFECTS OF THE COMPATIBILITY PROPERTIES OF
TO-BE-IGNORED STIMULI ON RESPONDING TO A TARGET.**

Thesis submitted for the degree of
Doctor of Philosophy
at the University of Leicester

by

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The Effects of the Compatibility Properties of To-Be-Ignored Stimuli on Responding to a Target.

Lorraine Bell BSc (HONS) MSc

Abstract

The compatibility effect found in the flanker task is usually explained in terms of response slowing due to incompatible flanker properties. It is as yet unclear whether the compatibility effect is also due to facilitative effects associated with compatible flanker properties. An extension of the Continuous Flow model put forward by Eriksen & Schultz (1979) namely the "Accumulated Activation Strength Difference" (AASD) model is proposed that maintains both response facilitation - due to compatible flanker properties, and response slowing - due to incompatible flanker properties, takes place under conditions where there is response competition. A series of flanker task experiments were conducted that presented 2, 4 or 6 flankers and combined flanker types in terms of their compatibility. It was found that flanker conditions that contained an equal number of compatible and incompatible flankers generated faster RTs than conditions that contained purely incompatible flankers. There was also no difference in RTs for incompatible flanker conditions or compatible flanker conditions whether there were 2, 4 or 6 flankers. This suggests that the effects of compatible and incompatible flankers cancel each other out. Furthermore, another experiment varied the ratio of compatible to incompatible flankers in a 4 flanker array. It was found that the ratio of compatible to incompatible flankers within a stimulus array mediates the magnitude of the compatibility effect. There is some evidence that this effect also occurs across different stimulus dimensions. The model also offers an explanation for why no response facilitation is observed for compatible trials compared to target alone trials and can account for how the patterns of errors in flanker tasks usually mirror the RT data. However, the model is incomplete, for example, it makes no attempt to account for how neutral flanker properties affect responding.

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Contents

Chapter 1: Introduction	1
1.1 Research Interests	1
1.2 The Effects of To-Be-Ignored Stimuli on Responding to a Target	1
1.3 The Flanker Task	2
1.4 The Compatibility Effect	4
1.5 Facilitation and Inhibition from To-Be-Ignored Stimuli	4
1.6 Physically Similar Flankers and their Effect on RT	8
1.7 Intrinsic Properties of Flankers	9
1.8 Relative Size and Contrast of the Flankers in Relation to the Target	12
1.9 Irrelevant Learned Associations Between Flankers and Target	13
1.10 Psychophysiological Evidence Associated with the Compatibility Effect	15
1.11 Accuracy of Responding	17
1.12 Speed/accuracy trade-off (SAT)	18
1.13 More than One Stimulus Dimension and Compatibility	20
1.14 Strength of Activation According to Attention	32
1.15 Spatial Separation and Automatic Attention	33
1.16 Negative Priming	41
1.17 Summary of the Literature	43
1.18 Implications of the Studies	48
Chapter 2: Models of Information Processing	50
2.1 Models Explaining Redundancy -Gain	50
2.2 Models Explaining the Compatibility Effect	52
2.3 Models Explaining how More than One Stimulus Dimensions Affects Responding	58
Chapter 3: The Accumulated Activation Strength Difference Model	67
3.1 Response Channel Activation and Response Priming	68
3.2 Response Execution	69
3.3 Strength of Target Activation	72
3.4 Processing Time and Accumulation of Activation Strength Difference	73
3.5 How the AASD Model Explains Patterns of Errors in Responding	79
3.6 How the AASD Model Explains the Compatibility Effect	80
3.6.1 <i>Inhibition from Incompatible Flanker Properties</i>	81
3.6.2 <i>Facilitation from Compatible Flanker Properties</i>	83
3.7 More than One Stimulus Dimension	85
3.8 Summary	87

4.1	Predictions for the Ordering of the Mean RTs of the Compatibility Conditions	90
4.2	Predictions for the Percentages of Errors Generated	96
4.3	Experiment 1: Method	96
	4.3.1 <i>Participants</i>	96
	4.3.2 <i>Apparatus and Stimuli</i>	96
	4.3.3 <i>Design</i>	96
	4.3.4 <i>Procedure</i>	101
4.4	Experiment 1: Results	102
	4.4.1 <i>Analysis of Reaction Times</i>	102
	4.4.2 <i>Comparisons of the Compatibility Condition with 2, 4 and 6 Flankers</i>	107
	4.4.3 <i>Analysis of Errors</i>	107
	4.4.4 <i>Discussion</i>	107
4.5	Experiment 2: Method	109
	4.5.1 <i>Participants</i>	109
	4.5.2 <i>Apparatus and Stimuli</i>	109
	4.5.3 <i>Design</i>	109
	4.5.4 <i>Procedure</i>	111
4.6	Experiment 2: Results	111
	4.6.1 <i>Analysis of Reaction Times</i>	111
	4.6.2 <i>Comparison of the Compatible Condition for 2, 4 and 6 Flankers</i>	115
	4.6.3 <i>Analysis of Errors</i>	116
	4.6.4 <i>Discussion</i>	118
4.7.	Experiment 3: Method	119
	4.7.1 <i>Participants</i>	119
	4.7.2 <i>Apparatus and Stimuli</i>	119
	4.7.3 <i>Design</i>	119
	4.7.4 <i>Procedure</i>	120
4.8	Experiment 3: Results	121
	4.8.1 <i>Analysis of Reaction Times</i>	121
	4.8.2 <i>Comparison of the Compatible Condition with 2, 4 and 6 Flankers</i>	124
	4.8.3 <i>Analysis of Errors</i>	124
	4.8.4 <i>Discussion</i>	126
4.9	Experiment 4: Method	128
	4.9.1 <i>Participants</i>	128
	4.9.2 <i>Apparatus and Stimuli</i>	129
	4.9.3 <i>Design</i>	129
	4.9.4 <i>Procedure</i>	129
4.10	Experiment 4: Results	129
	4.10.1 <i>Analysis of Reaction Times</i>	129
	4.10.2 <i>Comparisons of the Compatible Conditions with 2, 4 and 6 Flankers</i>	132
	4.10.3 <i>Analysis of Errors</i>	133

4.10.4	<i>Discussion of results from Experiments 1-4</i>	136
Chapter 5:	The Ratio of Compatible to Incompatible Flankers	144
5.1	Experiment 5: Method	146
5.1.1	<i>Participants</i>	146
5.1.2	<i>Apparatus</i>	146
5.1.3	<i>Design</i>	146
5.1.4	<i>Procedure</i>	149
5.2	Experiment 5: Results	150
5.2.1	<i>Analysis of Reaction Times</i>	150
5.2.2	<i>Analysis of Errors</i>	152
5.2.3	<i>Discussion</i>	153
Chapter 6:	Two Stimulus Dimensions	156
6.1	Experiment 6:Method	157
6.1.1	<i>Participants</i>	157
6.1.2	<i>Apparatus</i>	157
6.1.3	<i>Design</i>	157
6.1.4	<i>Procedure</i>	160
6.2	Experiment 6: Results	161
6.2.1	<i>Analysis of Reaction Times</i>	161
6.2.2	<i>Differences Between the Colour and Shape Dimensions in RTs</i>	164
6.2.3	<i>Analysis of Errors</i>	167
6.2.4	<i>Discussion</i>	169
Chapter 7:	General Discussion and Conclusion	171
7.1	The AASD model	171
7.2	Differences in accumulated activation strengths	172
7.3	The ratio of compatible to incompatible properties	174
7.4	Inconsistencies between redundancy gain and flanker task studies	175
7.5	The activation strength of the target	176
7.6	Patterns of errors in responding	178
7.7	More than one stimulus dimension	178
7.8	Different types of compatibility	183
7.9	Inhibition of responding	184
7.10	Variable threshold	186
7.11	Speed and accuracy trade off	187
7.12	The problem of neutral flankers	189
7.13	Continuous versus discrete stage models	190
7.14	Conclusion	191
References		193
Appendices		216

List of Figures and Tables

List of Figures

Figure 1.	The Flanker Task	3
Figure 2.	The Accumulated Activation Strength Difference Model	78
Figure 3.	Examples of the Compatibility Conditions with 4 Flankers (<i>Exp 1</i>)	97
Figure 4.	Boxplot Showing the Outliers in the RT data (<i>Exp 1</i>)	103
Figure 5.	Possible Permutations for the Incompatible Flanker Locations (<i>Exp 5</i>)	149
Figure 6.	Examples of the Conditions (<i>Exp 6</i>)	158
Figure 7.	The Possible Combinations of incompatible shape and colour within the Flankers (<i>Exp 6</i>)	159

List of Tables

Table 1.	Calculations for the ordering of the means for 2 flankers (target activation strength 3 times that of an individual flanker)	94
Table 2.	Calculations for the ordering of the means for 4 flankers (target activation strength 5 times that of an individual flanker)	94
Table 3.	Calculations for the ordering of the means for 6 flankers (target activation strength 7 times that of an individual flanker)	94
Table 4.	Mean RTs (ms) in ascending order for all conditions (<i>Exp 1</i>)	104
Table 5.	Means in ascending order for the flanker conditions (<i>Exp 1</i>)	105
Table 6.	Differences between the compatibility conditions (<i>Exp 1</i>)	105
Table 7.	Mean RTs (ms) in ascending order for all conditions (<i>Exp 2</i>)	112
Table 8.	Mean RTs (ms) in ascending order for the compatibility conditions (<i>Exp 2</i>)	114
Table 9.	Differences between the compatibility conditions (<i>Exp 2</i>)	114
Table 10.	Mean percentage of errors in ascending order for all conditions (<i>Exp 2</i>)	116
Table 11.	Differences between the compatibility conditions with 2 flankers	117
Table 12.	Differences between the compatibility conditions with 4 flankers	117
Table 13.	Differences between the compatibility conditions with 6 flankers	117
Table 14.	Mean RTs (ms) in ascending order for all conditions (<i>Exp 3</i>)	121
Table 15.	Mean RTs (ms) in ascending order for the compatibility conditions (<i>Exp 3</i>)	122
Table 16.	Differences between the compatibility conditions (<i>Exp 3</i>)	123
Table 17.	Mean percentage of errors for all conditions in ascending order (<i>Exp 3</i>)	124
Table 18.	Mean percentage of errors in ascending order for the compatibility conditions (<i>Exp 3</i>)	125
Table 19.	Differences between the compatibility conditions (<i>Exp 3</i>)	126
Table 20.	Mean RTs (ms) in ascending order for all conditions (<i>Exp 4</i>)	130
Table 21.	Mean RTs (ms) in ascending order for the compatibility conditions (<i>Exp 4</i>)	131
Table 22.	Differences between the compatibility conditions (<i>Exp 4</i>)	132

Table 23.	Mean percentage of errors in ascending order for all conditions (<i>Exp 4</i>)	133
Table 24.	Mean percentage of errors in ascending order for the compatibility conditions (<i>Exp 4</i>)	134
Table 25.	Differences between the compatibility conditions (<i>Exp 4</i>)	135
Table 26.	Differences between the compatibility conditions with 2 flankers (<i>Exp 4</i>)	135
Table 27.	Differences between the compatibility conditions with 4 flankers (<i>Exp 4</i>)	136
Table 28.	Differences between the compatibility conditions with 6 flankers (<i>Exp 4</i>)	136
Table 29.	Mean RTs (ms) in ascending order for all conditions (<i>Exp 5</i>)	150
Table 30.	Differences between each condition (<i>Exp 5</i>)	151
Table 31.	Mean percentage of errors in ascending order for all conditions (<i>Exp 5</i>)	152
Table 32.	Differences between the mean percentages of errors for each condition (<i>Exp 5</i>)	153
Table 33.	Mean RTs (ms) in ascending order for all conditions (<i>Exp 6</i>)	161
Table 34.	Differences between each condition (<i>Exp 6</i>)	162
Table 35.	Mean RTs (ms) in ascending order for 1 or 2 incompatible shape or colour conditions (<i>Exp 6</i>)	164
Table 36.	Mean percentage of errors in ascending order for all conditions (<i>Exp 6</i>)	168
Table 37.	Differences in percentages of errors between the conditions (<i>Exp 6</i>)	168

CHAPTER 1

INTRODUCTION

1.1 Research Interest

This research is based in the field of Cognitive Ergonomics and is concerned with how to-be-ignored or irrelevant information affects the responding to a target. This research can be applied to any environment where speed or accuracy are of importance and could be used as an aid to designing interfaces that require fast and accurate responding. Specifically, this research is concerned with compatibility issues. There is a wealth of literature examining what is known as the compatibility effect, but much of this research looks at the compatibility of stimuli in relation to response requirements. Generally this type of research is referred to as Stimulus-Response Compatibility (S-R compatibility). The research presented here, however, examines Stimulus-Stimulus Compatibility (S-S compatibility). S-S Compatibility is concerned with the compatibility of to-be-ignored stimuli in relation to a target stimulus rather than to the response requirements.

1.2 The Effects of To-Be-Ignored Stimuli on Responding to a Target

Research has shown that irrelevant or to-be-ignored stimuli (unattended stimuli) that are within the visual attentional field, are processed to the extent that they affect responding to a target. Furthermore, it has been shown that the properties of the to-be-ignored stimuli mediate the extent to which they affect responding to a target. Much evidence for the effects of to-be-ignored stimuli on responding to a target

comes from what has come to be known as the compatibility effect. The compatibility effect is usually observed in flanker tasks.

1.3 The Flanker Task

The flanker task is a simple choice reaction time task that typically involves the presentation of a target that is flanked either side by an equal number of to-be-ignored stimuli (also referred to as distractors and noise, but for the purpose of consistency they will be referred to as flankers throughout this thesis). Participants are typically instructed to respond as fast as possible by making a left or right button press according to the identity of the target whilst ignoring the flankers. Flankers are therefore the to-be-ignored stimuli in the flanker tasks (see Figure 1 below for an illustration of the flanker task). Early flanker task studies (i.e. Eriksen & Eriksen 1974; Eriksen & Eriksen 1979; Eriksen & Schultz 1979) used letters as stimuli. Eriksen & Eriksen (1974), for example, required participants to make a left button press if the target was one specified letter and a right button press if the target was another specified letter.

Flankers can be categorised in terms of their compatibility in relation to the target. Flankers whose properties are associated with the same response as the target (i.e. flankers that are identical to the target) are called compatible flankers, whereas flankers whose properties are associated with an opposite response to the target (i.e. flankers that are mapped onto an alternative response to the target) are called

incompatible flankers. Some flanker tasks may specify more than one stimulus for a particular response and thus two or more stimuli are mapped onto the same response. In such trials, it is possible to have compatible flankers that are not identical to the target.

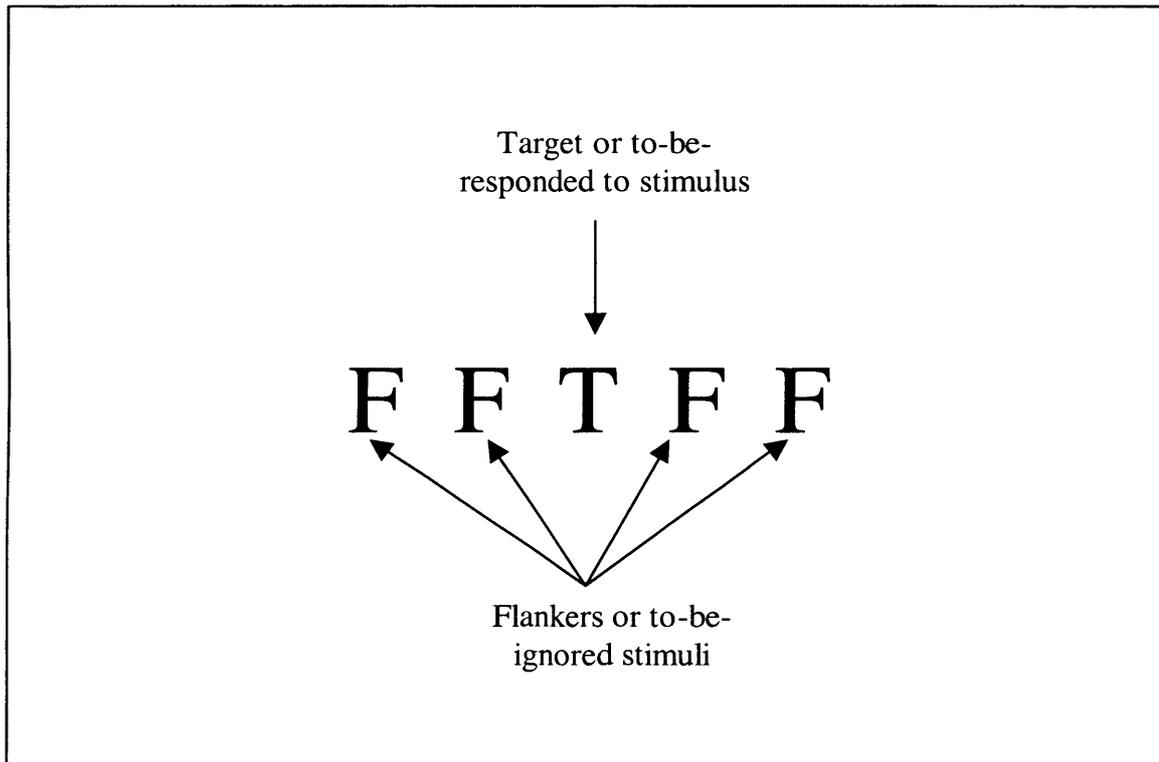


Figure 1. The Flanker Task

Furthermore, flankers whose properties are not associated with any specified response are called neutral flankers. What is interesting about the flanker task is that the properties of the flankers themselves mediate the extent to which they affect responding to the target. That is, the compatibility of the flankers in relation to the target, mediate reaction times (RTs) in responding to the target.

1.4 The Compatibility Effect

Since the early flanker task studies (for example, Eriksen & Eriksen 1974; Eriksen & Eriksen 1979; Eriksen & Schultz 1979) it has been well documented that incompatible flanker trials produce longer RTs than compatible flanker trials (flankers which are either identical to the target or belonging to the same response set as the target). Furthermore, neutral trials produce an intermediate effect on RT. That is, neutral trials produce longer RTs than compatible trials but shorter RTs than incompatible trials. Cohen & Shoup (1993) showed that there is a greater difference in the RTs between the incompatible and the neutral conditions compared to the difference between the compatible and neutral conditions.

In the flanker task literature, the compatibility effect is a term usually used to describe the response slowing associated with incompatible flanker trials compared to compatible flanker trials. It is not always clear whether the compatibility effect also refers to the intermediate effect that neutral flankers have on RT. The compatibility effect will be used here to refer to the longer RTs observed in incompatible flanker trials compared to the compatible flanker trials.

1.5 Facilitation and Inhibition from To-Be-Ignored Stimuli

There is general agreement that incompatible and neutral flankers inhibit responding to a target and that this inhibition is at least partly, if not entirely, responsible for the

increase in RT observed in incompatible and neutral trial conditions. However, no research has been conducted that examines whether there is an additive effect on RT of the number of incompatible flankers within a stimulus array (with the exception of a recent study by Fournier, Bowd & Herbert 2000 who looked at the number of incompatible features in flankers across different stimulus dimensions and which required participants to judge the presence or absence of features in a target letter. This is described later in section 1.13). That is, are RTs slower when there are more incompatible flankers compared to fewer incompatible flankers?

It is also not yet clear whether the compatibility effect may also be partly due to compatible flankers facilitating responding to the target. Sometimes flanker task studies include target alone trials to determine whether the presence of compatible flankers has a facilitative effect on RT. By comparing target alone trials to compatible flanker trials, such experiments can determine whether repetitions of the target within a stimulus array serve to decrease RT.

Generally, flanker task studies have found no difference in RTs between target alone trials and compatible flanker trials (see Smid, Mulder & Mulder, 1990, for a good review and study). Furthermore, Eriksen & Eriksen (1974, 1979) found no evidence of facilitation of RT with flankers that were either physically similar to, or identical to the target, or whether the flankers belonged to the same response set as the target (some studies show that flankers that are physically similar to, or belong to the same

response set as the target produce the compatibility effect, see section 1.6 later). However, there is evidence obtained in letter detection studies that suggest that the more compatible stimuli/flankers there are in an array, the quicker the RTs are in responding.

Letter detection tasks (also known as visual search tasks) differ from flanker task studies in that they require participants to make a response based on the identity of a target that may appear among other stimuli in an imaginary circular array around a fixation point where the position of the target is precued before stimulus onset. The number of flankers in the stimulus array can vary and the number of flankers that are identical to the target also varies. Flankers that are identical to the target are called redundant targets. The flankers in a letter detection task are usually either neutral (often referred to as noise stimuli) or are redundant targets. Any facilitation in RT due to redundant targets is called redundancy gain.

A number of letter detection studies (for example, Holmgren, Juola, & Atkinson 1974; Van der Heijden 1975; van der Heijden, Heij & Boer 1983) have shown that responses to trials that have a repetition of the target within them (redundant targets) are quicker than if the target is presented alone. Furthermore, the number of redundant targets is thought to reduce the RTs in responding proportionately. Van der Heijden (1975) for instance, found a decrease in RT as the number of repetitions of the target within a stimulus array increased.

Other letter detection studies have found evidence that repetitions of the target within a stimulus array leads to a decrease in RT in responding (Grice & Gwynne 1987 and Grice, Canham & Gwynne 1984 for example) and that this effect was greater when the target was accompanied by neutral flankers. However, these studies explain the decrease in RT with increasing repetitions of the target in terms of each repetition of the target taking the place of a possible noise flanker (by noise flanker they mean a flanker which is not the same as the target) as opposed to the compatible flankers actually facilitating responding to the target per se. That is, compatible flankers are only seen as being facilitatory to the extent that they reduce interference from neutral flankers.

Flanker task studies thus far, have not examined RTs in terms of the number of compatible or incompatible flankers within an array. Therefore, the notion of noise reduction has not been tackled adequately in compatibility studies. It may be fair to suggest, based on the studies reported above, that compatible flankers only facilitate RTs in responding when there are also compatible or neutral flankers within a stimulus array. It could be for example, that no facilitation is needed when there are no 'noise' flankers, but, when there are noise flankers present, compatible flankers might serve to facilitate responding to a target.

This research will examine whether redundancy gain is observed when there is a combination of compatible and incompatible flankers within a stimulus array. It is thought that any facilitatory effects of redundant flankers are manifest in response competition. That is, a redundant target does not serve to facilitate RTs when there are no instances of neutral or incompatible properties within a stimulus array. When there is a mix of compatible and incompatible flankers however, it is thought that the ordering of RTs in responding can be predicted in terms of the ratio of compatible to incompatible flanker properties within a stimulus array. This idea has parallels with Signal Detection Theory in that responses are seen as being determined by signal to noise ratios. This hypothesis is explained more fully when describing the Accumulated Activation Strength Difference Model later.

1.6 Physically Similar Flankers and their Effect on RT

Not only do incompatible and compatible flankers affect RTs in responding to the target, but flankers that have similar physical features to incompatible and compatible flankers also affect RT. Eriksen & Eriksen (1974, 1979) and Yeh & Eriksen (1984) found that target letters that were flanked by letters that had similar features to a letter calling for a competing response to the target, generated longer RTs than when the flankers were letters which had similar features to a letter associated with the same response as the target. The extent of the similarity of the flankers to the targets has been shown to mediate the size of the effect. Cohen & Shoup (1997) for instance, found that the compatibility effect was larger when the compatible trials

consisted of identical flankers to possible targets compared to flankers that belonged to the same response set, but were physically dissimilar. They also used target sets that used a letter and a number and found that the compatibility effect can occur when the target and flankers belong to different categories (i.e. letters and numbers).

The studies reported above refer to the physical similarity between target and flanker features. However, the similarity effect has also been observed in terms of semantics. Yeh & Eriksen (1984), for example, manipulated the similarity of the flankers both in terms of their physical similarity with the target and in terms of name code similarity. Trials were manipulated so that the flankers could have: the same name code as the target, but have no similar physical features with the target (e.g. a A a); the same name code as the target, but have similar physical features to a flanker that calls for a competing response to the target (e E e, where “e” shares similar physical features with a letter calling for a competing response to the target i.e. “a”); or could have both the same physical features and name code as the target (A A A). They found facilitatory effects of flankers that shared the same name code as the target even though the flankers had no physical feature overlap with the target. Furthermore, they found that RTs to trials where the flankers had the same name as the target were increased if the flankers also had physical similarity to a letter that called for a competing response.

1.7 Intrinsic Properties of Flankers

Rösler & Finger (1993) also found that similarity modulates the compatibility effect. They used combinations of letters, slashes and arrows as possible targets and flankers. They manipulated the flankers to be either perceptually similar or dissimilar to the target, as well as examining the effect of whether the flankers belonged to the same response set or not as the target. It was thought that the slashes and arrows have an intrinsic association with a directional response. It was assumed therefore, that an arrow or slash pointing to the right should prime a right hand response regardless of the stimulus-response mapping specified by the instructions. Thus, it was possible to have dis/similar flankers that were associated with one response as defined by the task instructions, but also to have perceptual similarity to the alternative response based on the intrinsic perceptual properties associated with the stimulus. They found that the compatibility effect was greatest when the arrows were flankers rather than when slashes or letters were flankers. This suggests that the compatibility effect can be mediated by the salience of the intrinsic properties of flankers to prime a given response.

Similarly, Fournier, Scheffers, Coles, Adamson & Abad (1997), used letters, slashes and arrows as stimuli and found that responses to arrows were quicker than responses to slashes and letter targets. They also found that increasing the perceptual similarity of letters increases the compatibility effect, whilst for slashes and arrows, the degree of intrinsic mapping of the flankers mediates the compatibility effect. Thus, the higher the intrinsic association between the stimulus and the

response, the faster the RTs are in responding. Other tasks have illustrated how the strength of the intrinsic association between stimuli and a response affect responding.

Barber and O'Leary (1997) explained how the intrinsic properties of a stimulus affect responding. They recognised two sources of activation generated from a stimulus: intentional activation, generated by the processing of the task relevant properties of a stimulus in order to make a response, and those generated by the intrinsic properties of a stimulus. Barber & O'Leary (1997) suggest that the salience of these S-R associations (both intrinsic and task specific) mediate the strength of the activation omitted.

Similarly, Ridderinkhof (1997) noted that the greater the S-R association strength, the stronger the potency of the stimulus to activate the corresponding response. Thus, a right pointing arrow would expect to have a greater potency in activating a right location response than an arbitrary shape mapped onto a right location response. Lu (1997) also suggested that the S-R association could mediate both the strength and the speed of activations omitted.....

“The stronger S-R association produces not only stronger, but also faster, activation than does the weaker S-R association” p108

It is thought that the intrinsic directional properties of a stimulus automatically prime the corresponding response even though the information is irrelevant to the task.

Eimer (1995) for example, argued that arrows tend to activate the corresponding response automatically. Furthermore, Ridderinkhof, Geesken & Band (1995) examined the compatibility effect using arrows and found that indeed, right-pointing flankers primed a right-hand response irrespective of the stimulus response mapping defined by the task instructions. Furthermore, they found that if the response mapping was against the natural intrinsic direction indicated by the arrows (i.e. a left-hand response to a right-pointing arrow and vice versa) then, response slowing due to incompatible flankers was reduced. They explained this in terms of the incompatible flankers priming both the incorrect response (due to the S-R mapping specified by the task instructions) and the correct response due to their intrinsic association with a directional response.

1.8 Relative Size and Contrast of the Flankers in Relation to the Target

Differences in the size of the stimulus also play an important role in mediating the compatibility effect. Eriksen & Schultz (1979) for example, showed that the relative size or contrast of the target in relation to the flankers mediate the strength of the compatibility effect. They observed an increase in RT when the target was small and of a reduced contrast compared to the flankers and that this effect was more pronounced in incompatible trials.

Ridderinkhof, van der Molen & Bashore (1995) also manipulated both the target size and compatibility of the flankers in relation to the target. However, they also

manipulated the S-R compatibility i.e. for incompatible responses a right response was required to a left pointing arrow. Their results showed that responses were faster with large targets and also that responses were faster when compatible responses compared to incompatible responses were required. Furthermore, for compatible flanker trials (compatible flankers to the target), the cost of making an incompatible response (response incompatible to the intrinsic properties of the target) was larger when the target was small and the cost of making an incompatible response when the flankers were incompatible was less great when the target was small. Thus it seems that the information regarding the size and the compatibility of flankers interact in that the cost of incompatibility is greater for smaller targets.

1.9 Irrelevant Learned Associations Between Flankers and Target

The Simon Effect shows that irrelevant (not task relevant) information about a stimulus can influence responding. The Simon effect shows that the spatial location information (relative to the mid-body line) about a target influences responding, even though the spatial location of the target is irrelevant to the task (see Simon 1969 and 1990 for examples). When the location of the target is congruent to the body side that a response is required (e.g. target presented on the left and a left hand response is required) responses are faster compared to when the location of the target and response side are incongruent. This is interesting because it shows that information that has no utility in making a response decision (i.e. does not provide any information that is useful for conducting the task) still influences responding.

Irrelevant learned information regarding correlations between flanker and target pairings has also been found to affect responding. Miller (1987) developed the correlational cuing paradigm that shows how irrelevant learned associations between the flankers and the target can prime responses. He used neutral flankers and manipulated the presentation rate of the flanker and target pairings. The target 'H' for example, might be presented with the neutral flanker 'R' in 92% of trials whereas another target 'I' might be presented with the neutral flanker 'P' in 92% of trials with the other 8% of presentations being the opposite pairings (P flankers with H target and R flankers with I target). He found that responses were faster to flanker/target pairings with higher presentation rates (and therefore higher probabilities) than when the flankers/target pairings had low presentation rates.

In a more recent experiment Miller (1998) manipulated the probability of a response by varying the presentation rate of particular targets within each experimental block. Participants were required to make one response to a 'C' and another response to the letter 'O'. The target 'C' for example, might occur in 75% of the trials within a block, leaving the target 'O' to be presented only on 25% of the trials. Miller found that responses were faster and more accurate for the higher probability responses compared to the lower probability responses. These studies show that irrelevant (incidental to the task) learned information regarding probabilities of flanker/target pairings and frequency of target presentations serve to prepare a response.

The above findings suggest that information that has no utility in making a response decision can still affect responding. Again, it suggests that even task irrelevant information, in terms of associations between the stimuli (flankers and target) and response, is used to prime responses. This suggests that all information regarding stimuli that can be linked to a response in anyway, automatically prepares that response. The preparation of a response has been demonstrated using physiological measures.

1.10 Psychophysiological Evidence Associated with the Compatibility Effect

Evidence from physiological studies have proved useful in the study of compatibility effects in that they have shown that not only are flankers capable of activating responses as indicated by electroencephalograms (EEGs) but also they can indicate whether a particular response has been prepared or not through observing electromyograms (EMGs) which measure isotonic or isometric changes in response relevant muscles. Such studies (Coles, Gratton, Bashore Eriksen & Donchin 1985; Rösler & Finger 1993; Eriksen & Schultz 1979 for examples) have shown that both the correct and incorrect response channels can be activated concurrently.

Such studies have also shown that the incorrect response channel is more likely to be activated when the stimulus array includes incompatible flankers than when it does not. Coles, Gratton, Bashore Eriksen & Donchin (1985) for example, found that

there is motor activation of the incorrect response hand with incompatible trials. Furthermore, Rösler & Finger (1993) found that incompatible flankers delay and compatible flankers slightly speed up, the onset of muscle activity and this was taken to indicate that incompatible flankers inhibit processing whereas compatible flankers facilitate it.

Lateralized Readiness Potentials (LRPs) are another physiological indication of response preparation. LRPs indicate which side of the brain has been activated in preparation for a response. Because of the reversal of the brain in terms of processing and action, one would expect the left side of the brain to be activated in preparation for a right side response and vice versa. Correct LRPs then, are when the opposite side of the brain to the direction of responding is activated. LRPs are measured as the onset latency of the first point in time that the lateralization is significantly bigger than zero.

Smid, Mulder & Mulder (1990) measured LRPs for participants undergoing a typical flanker task. They found more incorrect peripheral response activation for incompatible trials compared to compatible trials, and less for compatible trials compared to neutral trials. Also, peripheral response execution was faster and more accurate for compatible than target alone trials and slower and less accurate for incompatible trials compared to neutral trials. They concluded that flankers activate the corresponding response channels whilst stimulus evaluation is going on.

Furthermore, they found that the incorrect lateralization associated with incompatible trials started at the same time as correct lateralization for compatible trials.

Miller (1998), in the study described above, found that LRPs indicated that high probability responses were prepared before stimulus onset and it is this preparation of responding that he thought is responsible for the faster RTs for high probability responses compared to low probability responses. Thus, it seems that just anticipating a particular response, can prepare that response.

1.11 Accuracy of Responding

Not only do the properties of to-be-ignored information affect RTs in responding to a target, but they also affect the accuracy of responding to a target. Many studies involving the flanker task have been little concerned with patterns of errors in responding. This seems a little surprising considering the flanker task is one that is primarily concerned with RTs as a performance measure. However, many studies (Cohen & Shoup 1997; Fournier, Scheffers, Coles, Adamson & Abad 1997; Rösler & Finger 1993; Smid, Mulder & Mulder 1990 for example) report that the pattern of errors mirror that of RT. That is, there are a higher percentage of errors in incompatible conditions compared to compatible conditions.

These studies have been supported with physiological evidence generated using EEGs and EMGs. Such studies have shown that not only are flankers capable of activating responses as indicated by EEGs but they can also indicate whether a

particular response has been prepared or not through observing EMG studies (see Coles, Gratton, Bashore, Eriksen & Donchin 1985; Rösler & Finger 1993 and Smid, Mulder & Mulder 1990). Generally, such studies have shown that an incorrect response is more likely to be activated when the flankers are incompatible. Also compatible flankers slightly increase the likelihood of a correct response whereas incompatible flankers decrease it compared to the control condition (neutral noise). Rösler & Finger (1993), for example, found that the likelihood of errors increased with the presentation of incompatible flankers and decreased with compatible flankers.

The number of stimuli within an array has also been shown to influence accuracy in responding. The letter detection tasks mentioned in section 1.5 above for instance, found that there is higher accuracy in responding with trials that contain more repetitions of the target within them as opposed to fewer repetitions (Chastain, Cheal & Lyon, 1996, for example).

1.12 Speed/accuracy trade-off (SAT).

There is a wealth of studies that indicate that there is a trade off between speed and accuracy in performance for speeded tasks. Some studies for example, have reported that erroneous responses are usually faster than correct responses (see Laming 1968; Miller 1998). Furthermore, studies from the speed-stress paradigm (for example, Wickelgren 1977, and Wood & Jennings 1977) show that the percentage of correct

responses gradually increases with the amount of time allowed for processing stimuli. Thus, it seems that the value attached to speed or accuracy may be subjective. The idea that SAT is subject is supported by recent research by Norr (2000) that shows that speed and accuracy trade-offs differ greatly amongst individuals. Thus, there is evidence that the cut-off between the relative importance of speed or accuracy is not static rather, it can be modified by subjective decisions of the individual performing the task.

There seems to be a paradox when looking at speed and accuracy performance in the flanker tasks. On the one hand, RTs for incompatible flanker trials are found to be both slow and erroneous compared to compatible flanker trials. Conversely, compatible flanker trials produce both fast and accurate responses compared to incompatible flanker trials. Thus, SAT seems to break down when comparing performance across different conditions.

It is possible that there is a trade off between speed and accuracy within individual conditions of the flanker task. That is, there still may be a negative relationship between RT latency and the number of errors made in responding within conditions. There may also be an interaction between accuracy and the condition in the flanker task. Smid, Mulder & Mulder (1990) for instance, found that early responses are more inaccurate when the flankers are incompatible rather than compatible.

1.13 More than One Stimulus Dimension and Compatibility

The well known Stroop Effect (see Stroop, 1935, for the original paradigm) has shown that to-be-ignored information presented in one stimulus dimension can affect the responding to target information presented in another stimulus dimension. The classic Stroop task presents a colour word and participants are required to name the colour of the ink the word is written in whilst ignoring the other irrelevant dimension (the colour that the words spells). Sometimes Stroop like tasks use colour patches that are separate from the colour words (i.e. Brown, Roos-Gilbert & Carr 1995; Gatti & Egeth 1978; La Heij, Helaha & van de Hof 1993).

Stroop tasks show that the compatibility of the colour word to the ink colour affects responding to the ink colour that the word is written in. That is, responses are faster when the colour word is the same colour as the ink and slower when the colour of the ink and the colour word differ. This shows that the word information can affect the responding to colour information. Thus, information presented in one dimension (verbal in the case of the colour word) can interfere with the responding to information presented in another dimension (visual - colour of ink).

The Stroop effect is like the compatibility effect in that it shows that the compatibility of the to-be-ignored information (colour word) influences responding to the target information (colour of ink). The Stroop effect also shows that the to-be-ignored information does not have to be in the same dimension as the relevant target

information in order for it to affect responding to the target. Virzi & Egeth (1985) proposed the Translation model which attempts to explain how different dimensions of a stimulus (colour and word) can interact to affect RT. They suggested that each attribute of a stimulus is processed in a separate system (one system for processing colours and another system for processing words). They argued that interference would result if there is conflicting information within one system.

Virzi & Egeth explained the Stroop effect in terms of a translation of the ink colour information into the word system. When a vocal response to a colour patch is required for instance, the information about the ink colour has to be transferred into the word system. They argue that interference (response slowing) only occurs when responding requires a translation from one system to another that also contains potentially conflicting information within it. Thus, the information concerning the irrelevant colour word would cause RT slowing if it is incompatible with the target information.

However, the Translation model has come under scrutiny in the light recent research. Henik, Ro, Merrill, Rafal and Safadi (1999) conducted a flanker task using both colour patches and colour words as flankers and they varied the nature of responding to assess the merits of the Translation model. They presented a red or green square that served as a target stimulus in the centre of a screen that was flanked by either the word RED or GREEN or a series of Xs that were either red, green or a neutral

colour. Thus, the compatibility of the flankers could vary on two dimensions; colour-word compatibility or the compatibility of the ink colour. They required the participants to respond either manually or vocally so that they could manipulate whether the stimulus information would need translating from one system to another.

Henik et al. obtained the compatibility effect for both the colour of the ink and the colour word flankers for both manual and vocal responding which shows that the attributes of ink colour and colour word did affect RT even when translation from one system to the other was not required. Furthermore, they found an additive effect of the colour and word dimensions on RTs and also suggested that there is a hierarchy in terms of the propensities of information from different dimensions to affect responding. They found for instance, that the effect of coloured flankers on colour word targets is less than the effect that the colour word flankers have on coloured targets.

The translation model has come under further scrutiny in the light of research that has shown the Stroop effect to be uni-directional. When the task instructions specify a response based on the written colour name and not to the ink colour, the ink colour does not affect responding. That is, the ink colour does not influence the RT in reading the word. Lu (1997) pointed out that the Translation model could not account for the uni-directional Stroop effect and proposed an associative strength hypothesis that can account for the differences.

Lu argued that the strength of the stimulus-response association is based on two things; the perceptual similarity of the stimulus to the response; and whether the stimulus and response require the same processing system. A S-R association is said to be strong if the perceptual similarity between the stimulus and response is strong or if the stimulus and response require the same processing systems. Furthermore, the overall S-R association strength is stronger if there is both a strong S-R perceptual similarity and the stimulus and response use the same processing system compared to when the S-R association is strong in only one aspect. Lu argues that a compatibility effect (based on the irrelevant stimulus dimensions interfering with the relevant stimulus dimension) will occur only if the irrelevant S-R association is either equal to or stronger than the relevant S-R association:

“The correspondence effect [compatibility effect] of the irrelevant information [non response relevant dimension] is absent when the irrelevant S-R association is too weak to compete with the relevant one.” p102

Lu can account for the uni-direction effects found in Stroop and reverse Stroop tasks with calculations of associative S-R strength. Other theories have also used the S-R strength to account for such findings. Barber & O’Leary (1997) for example, argued that the S-R association strength mediates the activation strength generated by stimuli. Such theories suggest that different stimulus dimensions might differ in their propensity to affect responding.

Glaser & Glaser (1982) also put forward an argument that suggests that different stimulus dimensions might differ in their propensity to affect responding. They argued that differences in processing times of colour and word information might be responsible for the uni-directional affect of the Stroop tasks. It was thought that word information is processed faster than colour information. This theory can explain the uni-directional Stroop effect by arguing that the colour of ink information does not affect responding to word information because it arrives at the response stage too late (i.e. after the word information). However, when the task is to name the ink colour, the word information activates the corresponding responses before the ink colour information reaches the response stage. If the colour word and colour of the ink are compatible, then facilitation will occur due to the correct response having already received activation from the word information. Conversely, if the word is incompatible with the ink colour, its influence must be overcome to generate the correct response, leading to longer RTs for the colour-naming tasks.

The Stroop tasks are useful in that they show how information from colour and word stimulus dimensions interact with each other. Other studies have used other stimulus dimensions. Lavie (1997) for example, adopted both colour and shape as relevant stimulus dimensions. Participants were required to respond to either a green circle or a purple cross and not to respond if the target had any other combination. Thus, Lavie's study is a combination of a flanker task and a go – no go task. Lavie presented two flankers, one either side of the target under four conditions. For

compatibility conditions, the flankers either had both relevant dimensions of colour and shape embedded in the same object (a flanker was either a green circle or a purple cross with the other flanker having two neutral dimensions of colour and shape) or the dimensions of colour and shape were separated across the flankers (one flanker being a circle or a cross and the other flanker being green or purple respectively with the adjacent other dimension being neutral).

Lavie found no difference in the compatibility effect when flankers had the response relevant colour and shape dimensions conjoined or when they were disjoined. That is, Lavie found the compatibility effect when the relevant (not neutral) colour and shape were presented within one flanker as well as if the relevant colour and shape were presented in different flankers. She also found that the compatibility effect was not observed if there was only one relevant dimension present in the flankers. That is, if the flankers contained only one of the relevant dimensions (either a relevant colour or shape but not both with every other flanker property being neutral), then, there was no compatibility effect. This might be explained by extending Lu's (1997) theory that argued that the compatibility effect is absent if the irrelevant S-R strength is too weak to compete with the relevant S-R association. It may be for instance that the activation generated by one irrelevant flanker property is too weak to disrupt responding to the target (that should have both the relevant colour and shape combined).

That the compatibility effect is observed when the relevant colour and shape features are presented in different objects suggests that the dimensions that make up a flanker (such as colour and shape) are processed separately. Indeed, Smid, Mulder, Mulder & Brands (1992) and Smid & Heinze (1997) found evidence that the different dimensions of a flanker (in this case colour and letter) are processed separately. Also, Smid et al. (1992) and Smid & Heinze (1997) found that colour and letter information could activate the associated response before the letter is fully identified. Furthermore, various psychological, physiological and neuroanatomical studies have concluded that there is an initial segregation of the features from different dimensions in early processing of a visual stimulus (DeYoe & VanEssen, 1988, for a review).

Maruff, Danckert, Camplin and Currie (1999) used colour and letter as response relevant dimensions but conducted the typical flanker task. Their aim was to see whether the behavioural goals of the task were sufficient to constrain selective attention and therefore whether the properties of the flankers could be ignored. They required participants to either make a response based on the colour of a target whilst ignoring its letter, or to make a response based on the letter of the target whilst ignoring its colour. They hypothesised that if behavioural goals were sufficient to constrain selective attention, then only the goal (response)-relevant dimension of the flankers should influence responding.

Maruff et al. (1999) found that the colour dimension did not contribute to the compatibility effect when the instructions specified that the response should be based on the letter only, and, the letter dimension did not contribute to the compatibility effect when the instructions specified that responses should be based on colour only. Therefore, they did not find any additivity of activation generated by colour and letter when the instructions required a response to be based on either colour alone or letter alone. This suggests that the behavioural goals of the task were sufficient to constrain selective attention. That is, flanker properties that are not in the response relevant dimension, do not affect responding.

Similarly, Cohen & Shoup (1997) required participants to make one response to either a red colour or a right diagonal and another response to a green colour or a left diagonal. The responses were determined either by colour or orientation, but never both colour and orientation. They also had neutral flankers that were either red or green vertical lines or diagonal blue lines (that had one dimension that is relevant but never both). It was possible to combine the compatibility of the flankers across the stimulus dimensions of colour and line orientation. It was also possible for the compatibility of the flankers to be based on the same or different response relevant dimension as the target. They found that flanker properties only affected RT if the response relevant dimension was the same as the target i.e. both the target and flanker response relevant dimensions were either based on colour or both based on the orientation.

Both of the studies reported above suggest that information from different dimensions of a stimulus only affect responding if it is in the same dimension as the response relevant dimension as the target. This however, is contrary to the findings of the Stroop task that shows that stimulus properties that do not have any utility in making a response decision (i.e. the colour word) do indeed influence RTs in responding. Furthermore, there is evidence from a go - no go task that information across different stimulus dimensions is additive in nature. Mordkoff & Yantis (1993) for example, examined the effect of both colour and letter on RT in identifying whether a target attribute was present within a stimulus. They presented a letter and asked participants to make a 'go - response' (target attribute present) if a stimulus was either green, or the letter 'X' or both the colour green and letter 'X'. They found that RTs were quicker when the stimulus was both green and an 'X' than when either the letter 'X' or the colour green were the only response relevant attribute in the target stimulus. They argued that the activations generated from both the colour and shape information are combined and contribute towards response preparation. Thus, they found additivity across different stimulus dimensions in terms of their activations being pooled.

More evidence that the activation from different stimulus dimensions is additive is generated in a study by Fournier & Eriksen (1991). They required participants to judge the presence or absence of features of a target letter that was presented within

a circular array of distractor letters. The target letter varied across 3 stimulus dimensions: colour (red or green), shape (the letter S or C) and size (large or small). The discriminability of each of these dimensions was thought to vary with colour being the easiest to discriminate followed by the shape dimension (because the letters shared the same features) and then the size dimension. Participants were required to determine the presence or absence of one or more features within the target letter. They found that responses for one feature judgements were faster and more accurate for the colour dimension compared to the shape dimension and slowest and less accurate for the size dimension and this was thought to be due to the differences in their discriminability.

Moreover, they found that judging the presence of conjoined size and colour features and conjoined shape and size features was faster and more accurate than judging the presence of size alone. They also found that judging the presence of conjoined shape and colour features was faster and more accurate than judging shape alone. In addition they found that judging all three features of shape, size and colour produced the fastest RTs. The benefits associated with making judgments about the conjoined features have been put down to facilitation of the correct response due to faster priming of the most discriminable features (Fournier, Eriksen & Bowd 1998).

Fournier, Eriksen & Bowd (1998) proposed an Asynchronous Priming (AP) model (similar to Miller's asynchronous discrete model 1982a) to account for Fournier &

Eriksen (1991) findings as well as findings from their own studies. Similarly to Fournier & Eriksen (1991) they required participants to determine the presence of absence of features in a target letters based on either a specific colour (red or green for the colour dimension), or specific shape (the letters H or K for the shape dimension) or colour-shape conjunctions and they also manipulated the discriminability of each of the features. They again found that RTs for judging the presence of two or more features of an object can be faster and were more accurate than judging the presence of the least discriminable of these features alone.

The (AP) model accounted for these results by assuming that each stimulus feature is processed in parallel and in an independent fashion and that each feature primes its corresponding response. Furthermore, the activations generated from these features are thought to be combined, to meet response criteria and they assumed that highly discriminable features prime a response before less discriminable features. They therefore predicted that priming from less discriminable features will benefit from earlier priming from the more discriminable features when all the feature are mapped onto the correct response. Thus, the AP model predicts that when target features vary in terms of their discriminability, response priming can either facilitate or slow responding.

A follow up study by Fournier, Bowd & Herbert (2000) attempted to see if the AP model could be generalised to account for irrelevant stimuli (to-be-ignored flankers).

They also examined additive affects across different stimulus dimensions and differences in the stimulus features/dimensions to affect responding. Fournier, Bowd & Herbert (2000) presented flankers with the target letter and varied the compatibility features of the flankers in relation to the required response. They predicted that there is a cost of processing incompatible features because the priming of the incorrect response will need to be overridden. They also predicted the cost of incompatible information will be greater if the incompatible information is presented in one of the more discriminable stimulus dimensions. Thus, they predicted additivity in terms of the effects of the compatibility of information and the discriminability of that information. Thus, greater costs in responding should be observed for colour-shape conjunctions judgements when the more discriminable of the features is incompatible.

Fournier et al (2000) also predicted that when there are two incompatible flanker features, RTs would be slower than when there is only one or no incompatible flanker feature and that the effects of incompatible flankers features would be greater if they are in the same dimension as the relevant target features. Thus, if the task were to judge the presence or absence of the colour red in the target, responses would be slower if the incompatible flanker property is a green feature compared to when it is an incompatible shape feature. Thus, the propensity of the different stimulus dimensions to affect responding in terms of the discriminability and relevance of the flanker features (in terms of them being in the same dimension as the

relevant target dimension) as well as, the actual number of incompatible flanker features, are all seen to be producing additive effects on responding and this is what they found.

Given that different stimulus dimensions are processed separately and that they might differ in their processing speeds and activation strengths (according to S-R association strength and response relevance), then one may assume that different stimulus dimensions might not always interact with each other. This is because one of the stimulus dimensions might have a greater propensity to affect responding than the other. However, which stimulus dimensions have the greater propensity to affect responding is not yet clear. Some evidence from Stroop studies for example, found that words can affect responding to colours, but, colours do not affect responding to words (as mentioned earlier in section 1.13). This was taken to suggest that word information had a greater propensity to affect responding. However, others found that colours can affect responding to words (Henik, Ro, Merrill, Rafal, & Safadi, 1999, for example). The extent to which each stimulus dimension interacts with the other is an area that needs further research and clarification.

1.14 Strength of Activation According to Attention

Cohen, Dunbar & McClelland (1990) suggested that differences in the attention afforded response relevant and irrelevant information plays a role in the unidirectional effect of the Stroop tasks and the finding that only response relevant

information within an array affects responding. Response relevant information is thought to receive controlled attention and relatively strong processing compared to response irrelevant information that has only automatic attention and weak processing. The task demands are thought to determine what information receives controlled or automatic attention and it is argued that differences in attentional focus, along with the differences in the speed of processing of different stimulus dimensions, affect the strength of processing that stimuli receive.

Cohen et al. (1990) accounted for the Stroop tasks results according to the relative strengths of processing of the response relevant and response irrelevant information. Others have proposed that the activation of the target is enhanced by spatial attention simply because it is in the correct spatial location (Cohen, Servan-Schreiber & McClelland 1992; Eriksen & Schultz 1979; and Cohen & Shoup 1997).

1.15 Spatial Separation, Perceptual Load and Attention

The compatibility effect found in the flanker task using one dimension shows that unattended or to-be-ignored stimuli are processed to the extent that they affect response behaviour. This is contradictory to early selection theorists (see Broadbent, 1958, for example) who argue that filters early on in processing screen out irrelevant stimuli leaving only the relevant stimuli to go on for semantic processing. If the selection of relevant and the rejection of irrelevant information were to happen early on in processing then one would not expect to see the properties of flankers affecting

responding. The compatibility effect has indeed been explained in terms of the failure of the attentional system to screen out the flanker.

The notion of an attentional spotlight has also been used to account for how irrelevant information affects responding (Eriksen & Eriksen, 1974 for example). Yantis & Johnston (1990) adopted the spotlight metaphor of attention and argued that the compatibility effect observed in the flanker task is due to the “spilling over” of attention to the flankers. This spilling over of attention is thought to be due to low physical separation between the flankers and the target and the small resolution of the attentional spotlight. Indeed, the spatial separation of the flanker and the target has also been found to mediate the compatibility effect.

Studies such as those conducted by Eriksen & Eriksen (1974), Eriksen & Hoffman (1972, 1973) and Yantis & Johnston (1990) have showed that the spacing between the stimuli is important. The compatibility effect is reduced when the spatial separation between the flankers and target is increased (1° of visual angle and more). It is assumed that at larger distances, the flankers’ fall outside the spatial focus of attention and therefore the information from the flankers is not available.

Miller (1991) conducted a number of experiments to attempt to eliminate the compatibility effect in the flanker task by manipulating, amongst other things, the spatial separation between the flankers and the target. It was thought that at larger

distances the attention afforded the flankers will be reduced and that this would result in the absence of the compatibility effect. However, although the compatibility effect was reduced with larger spatial separation between the flankers and the target, the compatibility effect was not eliminated. Miller (1991) found the compatibility effect even with large spatial separation (5° of visual angle) between the flankers and the target. Miller concluded that increasing the spatial separation between the target and the flankers is insufficient to eliminate the compatibility effect.

Attention has also been thought to mediate the redundancy effect. Yantis & Johnston (1990) found no improvement on redundant target trials and no effect of the distance between identical letters suggesting that if attention is successfully focused, a redundant un-cued letter does not enhance performance even if it is adjacent to the cued letter. However, another letter-identification task conducted by Chastain, Cheal & Lyon (1996) ensured that the participants' focus of attention was directed towards the target position with the aid of a precue. They found that a target was identified with higher accuracy when there were more flankers that were identical to the target than when there were fewer flankers identical to the target.

Processing efficiency is also thought to vary across the visual attentional field (Anderson 1990 and Downing 1988 for examples) in that the processing efficiency is degraded at further eccentricities from the target information. Furthermore, the gradient of sensitivity is thought to be mediated both by the type of information that

is being processed and the spatial distribution of that information (Downing 1988; LaBerge & Brown 1989).

Other theorists adopted a zoom lens metaphor of attention (see Eriksen & St James 1986) where-by, the size of the visual attentional field can vary. Such an approach was adopted to account for findings that show that efficient stimulus processing can take place over either narrow or wide visual fields depending on the strategies undertaken in performing the task and the task demands them-selves (Gatti & Egeth 1978; Jonides 1983; LaBerge 1983, LaBerge & Brown 1986). Some theorists have argued that attention can be dynamically allocated (Eriksen & St James 1986; Eriksen & Yeh 1985) where the attentional resolution is inversely related to the width of the attentional beam. Treisman & Gormican (1988) for example found that the size of the spotlight expands as the difficulty of target discrimination decreases. Thus, flankers at the same distance away from a target are likely to have less effect on responding if the target or task requires strong attentional focus compared to when it requires weaker attentional focus. Some theorists, for example, have argued that the compatibility effect found in the flanker tasks is due to the automatic processing of flankers when the available attentional resources are not exhausted by the task. Lavie (1995) for instance argued:

“When the relevant stimuli do not demand all of the available capacity, irrelevant stimuli will unintentionally capture spare capacity, consequently enabling their processing”
p.452.

Later, in line with this, Lavie & Cox (1997) proposed that when the perceptual load of a task is sufficiently high, irrelevant flanker properties will not affect responding. They argued that tasks that place a high perceptual load on an individual, reduce the processing resources available to process task irrelevant information. This is not unlike the zoom lense metaphor of attention in that it also seems to suggest that the attention afforded the irrelevant flankers will vary as a function of the load placed on responding to the target.

It is not clear, however, whether the perceptual load of the task is determined in terms of how hard it is to respond to the target itself or whether the task conditions might also mediate the perceptual load. It might be for instance that there is a greater perceptual load when a response is required for incompatible flanker conditions compared to compatible flanker conditions' as there might be more resources required in terms of overcoming the conflicting information. Thus, it might be the case that the perceptual load of the task is mediated by: how hard it is to make the correct response, how hard it is to map the target onto the required response, the discriminability of the target amongst noise information, the sheer volume of information to be processed and the transformation needed to generate the required response.

Lavie & Cox's theory seems to capture the experiences that we have when trying to concentrate on a task or goal. When a task is hard, we make a conscious effort to screen out information that is not task related and that might interrupt our line of thought by attempting to direct all available processing resources to the task.

Lavie & Cox (1997) conducted a visual search study that required participants to respond to target letters that were presented within a circular array of letters. The target could either be easily identified from amongst the *distractor* letters (i.e. the distractor letters were visually dissimilar to the target) or the target was not easily identified amongst the distractor letters, (i.e. the distractor letters were visually similar to the target). The condition where the distractors were visually dissimilar to the target was thought to place a smaller perceptual load on the individual than the condition where the distractors were visually similar to the target. A letter was also presented outside of the circular display that was to be ignored. This letter was either compatible, incompatible or neutral in relation to the target.

Lavie and Cox (1997) found the compatibility effect when the distractors were dissimilar to the target but not when the distractors were similar to the target. They concluded that the perceptual load of the task was sufficiently large in the distractor similar condition that the to-be-ignored letter could actually be ignored. When the target letter could be easily identified within the circular array, the compatibility effect was observed because the perceptual capacity of the individual was not

exceeded and thus the properties of the to-be-ignored letter were processed automatically. Furthermore, they found that:

“ processing proceeds from relevant to irrelevant items until capacity runs out. With a low load in relevant processing, spare capacity inevitably spills over to process irrelevant information, and hence may lead to distraction. Irrelevant processing can be prevented only when a high load in relevant processing exhausts capacity.” p359.

Lavie and Cox (1997) conducted the same experiment again with the exception that they varied the number of distractor letters in the circular array. There were either 0, 1, 3 or 5 distractor letters presented on an imaginary circular array and they found that there was an abrupt decrease in distractor interference when there were more than 4 letters in the circular array. They point out that their results are consistent with previous studies that also show that the capacity limits are reached at around 4 to 5 letters (e.g. Fisher, 1982; Kahneman, Treisman & Gibbs, 1992; Pylyshyn, Burkell, Fisher & Sears 1994; Yantis & Jones, 1991). Thus, they defined perceptual load in terms of both the discriminability of the target and the amount of information that is to be processed.

Recent research by de Fockert, Rees, Frith and Lavie (2001) proposed that it is the demand placed upon working memory in a task that plays an important role in determining whether irrelevant information is processed to the extent that it affects responding to relevant information. They argued that working memory is used to

actively maintain stimuli that are task relevant. A high load placed on working memory would reduce the efficiency of determining the relevance of stimuli thus reducing the efficiency of selective attention. Thus, when there is a large amount of working memory resources taken up in conducting the task, the extent to which irrelevant information affects responding is also large.

Paquet & Craig (1997) examined whether it was possible to eliminate the compatibility effect in the flanker task under low perceptual load conditions. They used a target letter that was flanked by 2 flankers that were either the same category as the target (also letters) or belonged to a different category to the target (numbers). It was thought that flankers that belonged to a different category than the target are less likely to elicit the compatibility effect because there is a greater distinction between the flankers and the target than when flankers and target belong to the same category. They also manipulated the spatial distance between the flankers and target (3 and 5 degrees) and whether there was a fixation point to mark the location of the target before its presentation. For each of the above conditions, they also manipulated the flanker/target pairing presentations with correlations equal to .92 or .58 for high and low flanker/target pairings.

They were able to eliminate the compatibility effect with flankers at the furthest location from the target when the flankers either belonged to a different category as the target (digit flankers with letter targets) or when attention was precued to the

target location with the aid of the fixation point. They also found that using flankers that were not response alternatives (digit flankers to letter targets) was not sufficient to eliminate the compatibility effect because the high correlation pairings for flanking digits to target letters generated faster RTs than low correlation pairings. They concluded that it is possible to eliminate the compatibility effect under low perceptual load conditions and that using flankers that are not response alternatives is insufficient to eliminate the compatibility effect.

Gestalt grouping principals have also been found to mediate the compatibility effect. Many studies (Baylis & Driver 1992; Driver & Baylis 1989 and Kramer and Jacobson 1991 for examples) have found that the compatibility effect is larger when the target and flankers are part of the same group than when they are part of different groups.

The spatial separation, the perceptual load of the task and differences between automatic and focused attention as well as the working memory load have been put forward to explain how to-be-ignored information can affect responding to a target. Higher perceptual loads, larger spatial separation and more attention required by the target have all been thought to reduce the affects that irrelevant information has on responding to target or task relevant information.

1.16 Negative Priming

Negative priming studies show that the compatibility effect can be observed across trials. Negative priming studies are not unlike the flanker task in that they are choice RT experiments and they require a response to a target whilst ignoring flankers. Negative priming studies however, look at how a stimulus from a previous trial affects responding on a current trial. What they tend to show is that if a target was a flanker (or to-be-ignored) in a preceding trial, then, RTs are slowed in responding to the target. This slowing of RT is thought to occur due to residual inhibition from the previous trial that is carried over to the current trial. Negative priming was first observed in Stroop (1935) like tasks. It was noted that RTs to words drawn in a colour that the previous trial word spelled (the word being an irrelevant attribute) were longer than when the colour was not ignored in the previous trial (Tipper & Cranston 1985; Allport, Tipper & Chmiel 1985; Hasher, Stoltfus, Zacks & Rympa 1991; Neumann & DeSchepper 1991).

However, Moore (1994) pointed out that negative priming is not observed under all repetition trials. She stated that ...

“whether or not negative priming occurs seems to depend on characteristics of the irrelevant [distracting] aspect of the probe-trial [current trial] display. If an ignored-repetition probe trial [preceding trial] includes a distractor that conflicts with the correct response [that associated with an incorrect response], then negative priming occurs. If an ignored-repetition probe trial does not include a distractor that conflicts with the correct response, however, then negative priming may not occur.” p134.

Moore cites Lowe (1979, Experiment 4); Tipper & Cranston (1985, Experiment 3) and Allport et al. (1985, Experiment 9) as evidence of this but she also finds in her studies that.....

“negative priming will fail to occur on nonconflict probe trials only when they can be identified easily as including no information that could conflict with the correct response.” p143.

Thus, the negative priming studies show that the compatibility effect is observed across trials as well as within individual trials. It is generally assumed that negative priming is a result of the inhibition of to-be-ignored stimuli and that this inhibition has not corrected itself by the time the next trial comes around. Thus, it seems that the rate of decay of inhibition of a stimulus may be of issue. Negative priming studies have examined additivity of stimulus dimensions. A paper by Tipper & Weaver (1994) for example, examined negative priming and the additivity of the relevant stimulus properties. They found increased inhibition to probe trials with two as opposed to one of the stimulus properties being present within a distracter on prime trials. However, they also found that when three relevant stimulus properties are present within a distracter on a probe trial, facilitation in responding to the target in the prime trial occurs.

1.17 Summary of the Literature

The literature mentioned above is concerned with how irrelevant or to-be-ignored stimuli affect responding to a target. The evidence has mainly been generated from the flanker task and letter identification studies. What is consistent across these studies is that the presence of irrelevant or to-be-ignored stimuli that are associated with an alternative response to the target slows RTs in responding to the target and that this is within trials as well as across trials (as seen with negative priming). The compatibility effect has been examined using physiological indices that provide evidence that the activations generated by irrelevant or to-be-ignored stimuli are processed to such an extent that they can activate response channels. Physiological studies have generally shown that both the correct and incorrect response channels can be activated concurrently and that response muscles associated with an incorrect response are more likely to be activated with the presence of incompatible stimuli.

The compatibility effect has been observed with to-be-ignored stimuli that are physically similar to response relevant stimuli. That is, to-be-ignored stimuli that are similar to stimuli associated with an alternative response to the target will slow RTs and to-be-ignored stimuli that are similar to stimuli associated with the same response as the target will be relatively fast. The physical similarity studies have been taken to show that partial information about a stimulus can affect response correlates of behaviour. However, the similarity does not have to be in the stimulus dimension specified in the instructions. Studies have shown that similarity in terms of perceptual and semantic attributes of a stimulus also elicit the compatibility effect. Furthermore,

the Stroop phenomenon and studies using more than one stimulus dimension have provided evidence that information presented across stimulus dimensions can elicit the compatibility effect. This research has been taken to suggest that the activation generated from different stimulus dimensions is pooled at a response stage.

There is some evidence of additivity of the activation generated from different stimulus dimensions. Both flanker tasks and go - no go task have found that colour and letters have an additive effect on responding. Others have found that only the dimension that is the same as the response relevant dimension as the target affects responding. The present research accepts that the activation generated by different stimulus dimensions is pooled at a response stage and argues that the dimensions might differ in their propensity to elicit the compatibility effect due to possible differences in processing speeds and/or strengths of activation that they generate. However, it is thought that if two response relevant dimensions have the same processing speeds and activation strengths, then, their propensity to affect responding will be equal. Thus, RTs and error rates will be the same for when there are an incompatible shape and colour within the flankers as when there are either two incompatible shapes or two incompatible colours.

Additivity has also been examined within one stimulus dimension. In the flanker task studies the research has been limited to whether target alone trials differ to compatible flanker trials to see whether repetitions of the target within a stimulus

array facilitate responding. No facilitation was found. However, there is evidence from redundancy gain studies (letter detection studies) that repetitions of the target within a stimulus array facilitate responding and that the number of repetitions of the target has an additive effect on RT. It is thought the inconsistencies in the results may be reconciled if one assumes that facilitation, due to repetitions of the target, only occurs when a stimulus array also contains noise (neutral or incompatible) stimuli. However, this assumes that redundancy gain is merely due to noise reduction rather than facilitation.

The flanker task studies, as yet, have failed to examine whether there is an additive effect of the response slowing from incompatible flankers (with the exception of recent research by Fournier, Bowd and Herbert 2000). That is, are responses slower when there are more incompatible flankers compared to when there are fewer incompatible flankers. Furthermore, because no evidence of facilitation from compatible flankers has been found, the flanker task studies have also failed to examine whether the ratio of compatible to incompatible flankers mediate the magnitude of the compatibility effect. However, a model by Kornblum, Stevens, Whipple & Requin (1999) – DO 97 does contend that compatible flanker properties facilitate responding (by generating excitatory activation) and incompatible flanker properties inhibit responding. The DO 97 model also incorporates a function that takes into account the ratio of excitatory and inhibitory activation in predicting performance. This model is discussed in the next chapter.

The magnitude of the compatibility effect has been found to be mediated by the quality of the target in terms of intrinsic S-R associations, the size of the target in relation to the flankers and the physical similarity of the flankers. Thus, there are a number of factors that can contribute to the difference in RT between compatible and incompatible trials. Moreover, information from different stimulus dimensions (Stroop like tasks) and irrelevant information such as target location (the Simon effect) and correlational information have all been found to affect responding in terms of how they might facilitate or inhibit responding. It is assumed therefore, that information that can be associated with a response in any way (both task relevant and task irrelevant) is processed and to the extent that it affects responding. The DO 97 model mentioned above tackles the issue of how information from both task relevant and irrelevant stimulus properties are able to influence responding.

It is assumed that any information that can be related to a response generates activation that is pooled in the corresponding response channel. Furthermore, some studies (mentioned in section 1.8) have shown a superadditivity of the quality of the target stimulus and the properties of the irrelevant information in terms of their compatibility with the target response that supports these assumptions.

Finally, many studies have reported that patterns of errors in responding tend to mirror that of the RT data. However, error data is usually mentioned as a by-

product of RT with no attempt of an explanation to account for the origins of these errors or to account for the pattern of errors in responding.

1.18 Implications of the Studies

What is clear from the studies cited above is that not only do we process what we are attending to, but also we process information that we are instructed to ignore but which falls within our visual field. The flanker task shows how the properties of to-be-ignored stimuli are processed to such an extent that they affect RTs and error rates in responding. This suggests that to-be-ignored stimuli are not screened out at an early stage of processing.

This argument is further supported by studies that found that flankers that are physical similar to in/compatible flankers are able to produce the compatibility effect. This indicates that information generated by stimulus evaluation is passed on to the response channels before the full identity of the stimulus is available. Put another way, if a response is made only after the completed stimulus identity is formed, then it would be unlikely that partial information about a stimulus (i.e. the features that the flankers have in common with the response stimuli) would affect responding to a target. Thus, the finding that the similarity of the flankers with the response stimuli can affect responding is important because it suggests that information about a stimulus is passed on to response channels as it becomes available from stimulus evaluation processing.

The studies also seem to indicate that each stimulus is processed separately and the activation generated by each stimulus is pooled in response channels. Evidence for this comes mainly from redundancy gain studies conducted in the letter detection paradigm and those that examined how information from more than one stimulus dimension (both task relevant and irrelevant) affects responding. These studies show that RTs decrease and accuracy of responding improves as the number of compatible flanker properties within a stimulus array increases. Further support for pooled activation generated by the irrelevant information comes from studies that have show an additive affect on responding from two stimulus dimensions (mentioned in section 1.13).

Any model which attempts to explain the compatibility effect would have to account for not only the compatibility effect, but also the priming of responses from partial information generated by stimulus evaluation processing; the pattern and origin of errors in responding; the inconsistencies involved in the redundancy gain literature and the flanker task concerning whether compatible flankers have a facilitative effect on responding; and the pooling of activation generated from any stimulus dimension or irrelevant information that might prime a response. Chapter 2 presents some models that have been put forward to account for the compatibility effect found in the flanker task, redundancy gain and the pooling of information from more than one stimulus dimension.

CHAPTER 2

Models of Information Processing

There have been a number of models put forward to explain the compatibility effect. Some of the models specifically aim to account for the compatibility between stimulus response pairings or for all forms of compatibility (see Kornblum, Hasbroucq, & Osman's 1990 paper for a taxonomy and model of S-R compatibility). However, no model has specifically attempted to incorporate mechanisms that can account for both the patterns of errors and the inconsistencies in terms of redundancy gain in their models. The present research proposes a model that is being developed that attempts to account for the S-S compatibility effect found in the flanker task, the patterns of errors and the uncertainties as to whether compatible flanker properties facilitate responding or not. The models described here are specifically accounting for these aspects of information processing.

2.1 Models Explaining Redundancy-Gain

Two types of models have been put forward to explain the redundancy effect (or decrease in RT observed when more targets are present) associated with the letter detection tasks: Race models and Coactivation models (see Miller, 1982b, for an overview). Race models assume that each stimulus within an array is processed in one of many parallel channels. A response is made on the basis of one of those channels recognising that the target is present. That is, a response is made when the activation within any of those separate channels reaches the threshold level required

for a response. It follows that the more targets there are within a stimulus array, the greater the likelihood that a target response channel will reach the threshold activation level quickly and win the race. Race models therefore explain redundancy gain in terms of statistical facilitation due to an increased number of correct response channel activations taking part in a race.

Coactivation models on the other hand suggest that the signals within different channels generated from each of the stimuli can be pooled and this pooled activation initiates a response. The argument goes that a response based on combined activations from stimuli is likely to reach the required threshold level required for a response, quicker than any independent activation within a response channel. Coactivation models therefore, explain redundancy gain in terms of pooled activation for separate channels. Thus, coactivation models assume that there is an additivity of the activations generated by individual stimuli. Indeed Mordkoff & Yantis (1993) explained their finding that RTs were faster when both the response relevant colour and shape were present compared to when only one of the response relevant dimensions was present in terms of coactivation of the colour and shape information.

Of the two types of model, the coactivation models seem to be in a better position to explain the effects noted above. This is because it is easier to visualise how coactivation models may account for the activation of a response channel generated by partial information about a stimulus. Race models on the other hand, give the

impression that a response is based on the completed identity of the stimulus i.e. the fastest stimulus to *finish* processing is the one that response execution is based on. Coactivation models also seem to have greater potential to explain additivity. As mentioned earlier, the compatibility of colour and letter properties of a stimulus sometimes have an additive effect on RT. Coactivation models might explain this in terms of the pooling of information from different stimulus dimensions. It is less easy to see how race models may account for this additivity.

The debate on which of the two classes of models most accurately describes redundancy gain is ongoing and further models are being proposed. Mordkoff and Yantis (1991), for instance, suggest an Interactive Race Model that combines features of both the race and coactivation models. The Interactive Race Model suggests separate activation channels for each of the stimuli (parallel processing as seen in the race models) but also includes *cross talk* or information exchange between channels.

2.1 Models Explaining the Compatibility Effect

Eriksen & Schultz (1979) proposed the Continuous Flow model to account specifically for the compatibility effects associated with the flanker task. The Continuous Flow model maintains that all stimuli within a stimulus array are subject to stimulus evaluation processing in parallel. That is, the flankers and target will go through stimulus evaluation at the same time. It is thought that the information

generated from stimulus evaluation processing is passed on to the corresponding response channel in the form of activation. Compatible flankers and the target will give activation to the correct response channel and incompatible flankers will give activation to the incorrect response channel.

The Continuous Flow model also suggests that activation generated by stimulus evaluation processing is passed onto the corresponding response channel as soon as it becomes available. That is, there is a continuous flow of information/activation from stimulus evaluation processing to the response channels. Stimulus evaluation processing will continue until the accumulated activation in a given response channel reaches a threshold or criterion level of activation. A response is thought to be made when the threshold level of activation is reached within a response channel. The Continuous Flow conception of processing, therefore, suggests that a response can be made at anytime throughout the stimulus evaluation processing, providing that a threshold level of activation is reached.

The Continuous Flow model accounts for the compatibility effect by suggesting that when more than one response channel is activated concurrently, both (or all) response channels are inhibited from executing a response. It is this inhibition (called mutual inhibition) that is thought to be responsible for the slowing of RTs for incompatible flanker trials compared to compatible flanker because both the correct

response channel and the incorrect response channel will be mutually inhibited. The compatibility effect is then thought to be manifest purely in response competition.

While the Continuous Flow Model can account for response slowing with incompatible trials, the model is incomplete because Eriksen & Schultz (1979) do not go on to explain on what basis a response is made after mutual inhibition. The typical flanker task usually presents more flankers than targets (usually there is only one target). For incompatible flanker trials therefore, the activation generated by the flankers – and that received by the incorrect response channel, should exceed that in the correct response channel – yet we know that a majority the correct response is made even in incompatible flanker trials.

It is easy to see how the Continuous Flow model can adequately account for how partial information about a stimulus can affect responding (mentioned in section 1.6). The Continuous Flow model suggests that information that is generated throughout stimulus evaluation processing, is passed onto the corresponding response channels continuously and as soon as it becomes available. It is generally accepted that the individual features of a stimulus are processed separately. The letter 'H' for example is comprised of two vertical lines and one horizontal line and these lines (or features) are processed separately. The identity of the stimulus is arrived at by matching information about stimulus features against templates of items already stored. The two vertical lines and the horizontal line will be compared with the template of 'H'

(because it also has two vertical lines and one horizontal line) and when the match is made the identity of the stimulus is known.

It is also easy to see how the Continuous Flow model can account for how information from different stimulus dimensions (such as colour and shape) may go different dimensions of a stimulus (e.g. colour and shape) may influence responding. Because the Continuous Flow model can account for how partial information (i.e. feature information about a stimulus) about a stimulus can activate a response channel before the full identity of the stimulus is known, it might be fair to suggest, that any flanker property (such as colour and shape) that can be associated with a response in anyway, can also activate the corresponding response channel. Flankers that share features or dimensions in common with the target (or a stimuli mapped onto the same response as the target) will give activation to the correct response channel. Conversely, Flankers that share features or dimensions with an incompatible stimulus, will give activation to the incorrect response channel and will therefore cause mutual inhibition and consequently response slowing. Thus, the Continuous Flow model can account for how the physical similarity of flankers (in terms of shared features or dimensions to a potential targets) can affect responding.

It is also possible to see how continuous flow model can explain redundancy gain if one imagines that a response is based on coactivation model principles. If this is the case, then the more incidences of compatibility within a stimulus array, the more

activation is passed onto the correct response channel and it follows that the activation threshold criteria can be reached more quickly than if there were fewer incidences of compatible information within the stimulus array. That is, the activation from redundant flankers serve to increase the activation in the correct response channel and this enables the threshold level to be reached more quickly than if no redundant flankers were present. However, as noted earlier, facilitation due to redundant signals is only usually observed with the presence of noise stimuli (noise that is neutral or incompatible). This suggests that the threshold level of activation required for a response is smaller when only compatible information is present than when incompatible or neutral noise is present.

Furthermore, it is also possible to visualise how the Continuous Flow model can account for the finding that stimulus properties that are irrelevant to the task, (as seen in the Stroop task and the correlational cuing paradigm) may affect responding if connectionist theory is applied to the stimulus evaluation processing. However, the model fails to tackle the issues of patterns of errors in responding.

Later Cohen, Servan-Schreiber & McClelland (1992) adopted a Parallel Distribution Processing Approach to Automaticity that they used to put forward a network model that can account for the compatibility effect associated with the flanker task. Their network model comprises three modules, an input module, an attention module and an output module. The input module contains units, one for each stimulus in each of

the possible spatial locations within a stimulus array. The units in the input module have connections to the units in the output module (one unit for each possible response). The third module is an attentional module that contains units for each of the spatial locations of the stimuli. These units have connections to the units in the input module that share the same spatial location. The task instructions in the flanker task specify which stimulus location is to be attended to (i.e. the central stimulus) and this attention activates the corresponding unit in the attention module, which in turn enhances the activation in the corresponding units in the input module.

The connections between modules are excitatory only and the connections between the units in the attention module and the input module are bi-directional. They also assume that within each module, each unit inhibits every other unit. They account for the compatibility effect in terms of inhibition between units within modules and facilitation from units between modules. Facilitation is thought to be modulated by attention and by different weightings given to units within each module. Although this model can successfully account for the compatibility effect, it is very complicated and involves a number of mechanisms. The model presented here offers a simpler explanation of the compatibility effect observed in the flanker task.

Cohen, Servan-Schreiber & McClelland (1992) also offer a model to account for the Stroop effect based on their Parallel Distribution Processing Approach to automaticity that again is very complex. They argue that the interference effects

associated with the Stroop task are based on differences in strengths of processing and attentional modulation. Later models have also used the idea of strengths of processing and attention to account for the Stroop effect.

2.3 Models Explaining how more than One Stimulus Dimension Affects Responding

Cohen and Shoup (1997) proposed the Response Selection Model to account for their findings that the compatibility effect is not observed when the response relevant dimensions of the flankers differ to the response relevant dimension of the target (study described in the introduction section 1.13). Cohen & Shoup argue in line with evidence from psychological, neuroanatomical and neurophysiological studies, that early stimulus processing separates visual stimulus properties in terms of their dimensions (i.e. colour and shapes etc.) prior to any activation of the response selection process. The information contained in each group is analysed simultaneously. They argue that when a response is based on one stimulus dimension only, the information within that dimension affects responding because initial response selection is performed separately within each dimension.

Cohen & Shoup explain the slowing of responses when the target and flanker response relevant dimensions are associated with competing responses as being due to a retardation of the activation of the central response code. Conversely, there is no compatibility effect when the response relevant dimensions of the flankers differ from

that of the target because there is no competition between responses for features from different dimensions. However, they note that even when there is competing information within the response relevant dimension, the correct response is made a majority of the time. They account for this by arguing, along with others, that the activation of the target is enhanced due the target being in the correct spatial location and thus the correct response will 'win' a majority of the time.

Cohen & Shoup note that their model only accounts for situations where the response is based on only one of the stimulus dimensions. That is, there is no cross talk required between the dimensions when the response is based on only one dimension. However, there is evidence from Stroop tasks that irrelevant words affect responding to a relevant colour. There is also evidence from a go - no go task (Mordoff & Yantis 1993) that the colour and letter features of a stimulus have an additive effect on RT even when only one response relevant dimension is required for a response. Furthermore, Henik, Ro, Merrill, Rafal and Safadi (1999) conducted a flanker task and found an additivity of colour and word dimensions.

Fournier, Eriksen & Bowd (1998) and Fournier, Bowd & Herbert (2000) found evidence of additive priming effects when decisions regarding conjunctions of information across different stimulus dimensions were required. This was for task relevant features that were both in the target object and for features that were presented in to-be-ignored objects. They required participants to decide whether one

or more target features(s) (shape, colour and size) were present or absent within a target object and they also manipulated the discriminability of each of the different stimulus dimensions. They found additive priming effects for task relevant features that matched the task goals whether these features were presented within the target object as well as when they were embedded in to-be-ignored stimuli.

Fournier, Eriksen and Bowd (1998) proposed the AP model to account for how information from different stimulus dimensions and features can combine to affect responding (described in section 1.13). They suggested that models that assume parallel and independent processing of each task relevant stimulus feature and that the activations of each of these features primes their corresponding responses can account for their results.

There are a number of explanations for the inconsistencies between these experiments in terms of whether irrelevant stimulus dimensions (not response relevant) affect responding to a target. It could be something to do with the difference in perceptual loads demanded by the tasks. Lavie & Cox (1997), for instance, argued that processing continues from relevant to irrelevant properties. Similarly, Smid, Mulder, Mulder & Brands (1992) argued that priority judgements are made that select stimulus attributes which provide the highest utility in successful task performance. This seems like a feasible argument when the differences between the go - no go tasks and the flanker tasks are examined. The go - no go task for

instance usually present only the target, whereas the flanker tasks present a target and flankers. The fact that the flanker task presents more stimuli to be processed might be enough under the circumstances to render the perceptual load of the task sufficiently high in order for the irrelevant response dimension to be ignored.

Another problem with Cohen & Shoup's (1997) model is that it does not attempt to account for errors. Indeed they reported that the pattern of errors mirror that of RT but their model does not have any direct interpretation for the origin of these errors. However, the present research agrees with the Response Selection Model in terms of different stimulus dimensions being processed in separate systems, but, offers an alternative explanation of the mechanisms behind response execution to account for the compatibility effect. The model proposed here also offers an explanation for the patterns of errors and redundancy gain effects inherent in the model.

The model presented here however, does not make any assumptions about the processes involved in stimulus evaluation processing. No attempt is made to outline how the stimulus evaluation processing is carried out. Instead the writer points to models that offer very convincing accounts of stimulus evaluation processing such as the Cascade Model by McClelland (1979); The Activational Model by Barber & O'Leary (1997) and Cohen & Shoup's (1997) Response Selection Model.

The model presented here rejects the notion that the compatibility effect is manifest purely in inhibition when incompatible stimulus information is present in a stimulus array. Instead the model assumes that response execution is based on differences between activation strengths in competing response channels. Chapter 3 describes the Accumulated Activation Strength Difference model that is being developed. The model not only attempts to account for the compatibility effect found in the flanker task, but also, it aims to account for the inconsistencies in the literature as to whether compatible flankers have facilitative effects on responding and how the patterns of errors usually mirror RT data.

Another recent model by Zhang, Zhang & Kornblum (1999) is comprehensive in that it accounts for compatibility effects in many task paradigms. Zhang, Zhang & Kornblum's model also adopts the PDP approach put forward by Cohen, et al (1990) and can account for RT data in Stroop like and flanker tasks as well as Stimulus-Response (SR) and Stimulus-Stimulus (SS) compatibility tasks. This PDP also incorporates previous ideas expressed in the Dimensional Overlap model (DO) by Kornblum and his colleagues (Kornblum 1992, 1994; Kornblum, Hasbroucq & Osman 1990; Kornblum & Lee 1995) in terms of how the overlap between stimulus-stimulus (S-S) and stimulus-response (S-R) dimensions can predict compatibility effects generated within different task types. The overlap between different stimulus/response dimensions here refers to the similarity between them.

The Dimensional Overlap (DO) between stimuli and responses can be either task relevant (serve some utility on making a response) or task irrelevant (are not criteria for which a response may be based). Thus, task irrelevant information that overlaps with some relevant dimension (either other stimuli or a response) may have some affect on responding (The Simon effect for instance). Some studies combine S-S and S-R compatibility and found that the S-R and S-S compatible conditions generate the fastest RTs, the S-R and S-S incompatible conditions generate the slowest RTs and the S-R/compatible and S-S/incompatible and the S-R/incompatible and S-S/compatible conditions always generate intermediate RTs (Kornblum 1994 for instance). The various different configurations of S-S, S-R compatibility and relevant and irrelevant dimensions were categorised and the DO model could account for compatibility effects for each task type in the taxonomy adequately. Thus, the DO model is comprehensive as it accounts for compatibility effects found in many different compatibility task paradigms.

Zhang, Zhang & Kornblum's model assumes three layers of nodes (Input – Intermediate – Output) like the PDP approach put forward by Cohen, et al (1990) that work on both a continuous flow and parallel processing basis. That is, activation is passed on from lower level nodes onto later nodes and a response is made when the activation in an output node reaches a threshold level. Information processing goes through many successive cycles until the threshold is reached in one of the nodes in the output section and therefore activation is seen as increasing over

time. This PDP model also gives a larger weighting of activation to relevant stimulus dimensions and this can vary according to the level of attention paid to the relevant and irrelevant dimensions.

Zhang et al also adopt the notion of mutual inhibition. It is thought that mutual inhibition can take place between any layer (i.e. between the input and intermediate levels etc). The actual workings of the model are very difficult to summarise but it is very good at simulating many of the compatibility effects generated by the various forms of compatibility tasks outlined in the DO taxonomy. Furthermore, it can account for how activation from different stimulus dimensions (both task relevant and irrelevant) can be combined. Their model also assumes different weightings for different stimulus dimensions and in doing so can account for phenomenon like the reverse Stroop effect. However, this model only allows for the correct response to be made and does not account for patterns of accuracy.

Another extension of the DO model is put forward by Kornblum, Stevens, Whipple and Requin (1999). This model is known as DO 97 and is also very comprehensive as it can account for all types of compatibility (S-S and S-R compatibility) and it can also adequately account for how task irrelevant information affects responding. Like the original DO model, the DO 97 model consists of two stages: the stimulus-processing stage and the response production stage. The stimulus production stage is made up of modules that consist of groups of stimulus dimensions (e.g. colour,

shape, location etc.). Within each module are units that comprise the features of each module (i.e. units in a colour module would be the individual colours, i.e. red, etc.). The response-production stage also consists of modules that are made up of response relevant features (left and right key press for example).

Pathways exist between units that overlap that can be either excitatory or inhibitory. Pathways that are connected via incompatible units are inhibitory and pathways that are connected via compatible units are excitatory. Furthermore, the pathways that connect the stimulus to the corresponding response are thought to be controlled. However, pathways that link units with dimensional overlap, but, that do not have any utility in making a response decision, are called automatic pathways. The activation generated by both the relevant and irrelevant pathways is thought to be equivalent in the first instance. However, as time continues, the activation generated by the irrelevant stimulus units/properties is thought to decline.

The DO 97 model also makes the assumption that no activation is received by the response production stage (i.e. no processing takes place) until a unit in the stimulus-processing stage reaches a threshold level. Thus, the DO 97 model is a stage model in this respect. The DO 97 model also offers a good explanation of error generation that can account for how the patterns of errors usually mirror that of the RT data. The model explains the production of errors in terms of the probability of making an incorrect response based on the probability of the activation of an incorrect response

unit reaching the required threshold level. There is a greater likelihood that an incorrect response will reach the required threshold when there are more incompatible stimuli within an array as incompatible stimulus features generate activation that would both inhibit the activation build up of the correct response, whilst at the same time, contribute to activation of an incorrect response. Thus, the ratio of compatible to incompatible features within a stimulus array would influence the probability of making an erroneous response.

The DO 97 is very comprehensive and convincing, but, it is not beyond criticism. Firstly, the authors of the paper acknowledge that different stimulus dimensions might differ in their propensity to affect responding. They cite two studies (Hommel 1994; Shiu & Kornblum 1995) that have shown that colour and position information are processed at different rates. These studies assign different weights to colour and shape information when attempting to predict their affect on responding. The authors do not attempt to assign weights to information from different stimulus dimensions. Secondly, the DO 97 model would predict that there would be facilitation in responding when there are more compatible features within a stimulus array, regardless of whether the array also contains incompatible features. Thus, the DO 97 model does not attempt to account for the inconsistencies between the redundancy gain studies and the flanker task studies in terms of whether compatible flankers will facilitate responding or not.

CHAPTER 3

The Accumulated Activation Strength Difference (AASD) Model

The literature reported earlier indicates that the pattern of errors in responding generally mirrors the RT data (see earlier section 1.11). Most models put forward to explain the compatibility effect (with the exception of the DO 97 model) have neglected to account for this pattern of errors and there is very little scope for direct interpretation of the origin of these error patterns within the models. It is necessary when conducting compatibility studies that the pattern of errors which, accompany experiments having RT as a performance measure, to be of issue and that this is taken into account in the development of any model. Errors should not be dismissed as a by-product of RT tasks. Instead, errors should be accounted for as an integral part of any model explaining the compatibility effect. There is also no model that can account for the inconsistencies between the redundancy gain and the flanker task studies. Indeed, the flanker task literature does not make clear predictions as to whether compatible flankers should facilitate responding or not.

The following model attempts a more comprehensive explanation of the compatibility effect than previous models in that it offers an explanation for the patterns of errors observed in the flanker task as well as being able to make predictions as to whether compatible flanker properties will have facilitatory effects

on RTs or not. The present model also offers leverage to account for how information from more than one stimulus dimension may affect responding.

The AASD model presented here is an extension of the Continuous Flow model put forward by Eriksen & Schultz (1979). Like the Continuous Flow model, the AASD model assumes that all the stimuli (the target and flankers) are analysed according to properties associated with a response. Every stimulus within the attentional visual field is seen as contributing to response preparation. That is, all the stimuli within the attentional visual field generate activation that will prime the corresponding response channel depending on the stimulus properties. The activation generated from the target and compatible flankers properties would give activation to the correct response channel whereas, incompatible flanker properties would give activation to the incorrect response channel. Like the Continuous Flow model, the AASD model assumes that the activation generated by stimulus evaluation processing accumulates within the response channels.

3.1 Response Channel Activation and Response Priming

Also like the Continuous Flow model, the AASD model suggests that as activation is generated from stimulus evaluation processing, it is passed on concurrently and continuously to the corresponding response channels. That is, compatible flanker properties will give activation to the correct response channel and incompatible flankers properties will give activation to the incorrect response channel as the

information about the properties of a stimulus become available. Flanker properties might be in the dimension specified in the task instructions (task relevant) or might be task irrelevant. It is thought that information from any source such as from irrelevant stimulus dimensions, (seen in the Stroop like tasks mention in section 1.13) intrinsic S-R associations or learned associations (described in sections 1.7 and 1.9 respectively), that can be associated with a response in any way, will prime the corresponding response channel given that the perceptual load of the task is sufficiently small. The incidental activation generated due to task irrelevant information will be called aspecific priming here.

Cohen, Dunbar & McClelland (1990); Cohen, Servan-Schreiber & McClelland (1992) and Logan (1980) also used a continuous flow conception of information processing to account for how task irrelevant information in the Stroop tasks affected responding. They argued that partial information from both the task relevant and irrelevant information can prime the corresponding response and produce facilitation or interference.

3.2 Response Execution

Unlike the Continuous Flow model, the AASD model rejects the notion that response execution works on the basis of a threshold criterion level of activation being reached. Instead, the AASD model makes the assumption that response execution is based on differences in accumulated activation strengths between two

(or more) competing response channels. A response channel is defined here as the place where activation derived from stimulus evaluation processing is accumulated and which serves to prepare a given response. It is thought that the response channel that has the highest accumulated activation strength will be the one that eventually executes a response, but, a response is triggered by the accumulated activation strength difference between competing response channels rather than the activation within any one of the response channels reaching a criterion threshold value of activation.

The idea that response execution is based on differences between accumulated activation strengths is not novel. The difference between the activations of response nodes has been proposed as the basis for response execution. Van der Heijden (1981) for example, suggested that a threshold might vary as a function of the difference between activations of nodes. Similarly, Cohen, Dunbar & McClelland (1990) also suggested that a response is made on the basis of the difference in accumulated activation strength in response channels (or output nodes as they call them). However, they proposed that the difference had to exceed a static threshold level before a response is made whereas the model presented here suggests a variable threshold based on a sufficient difference in activation strengths between competing response channels and that this may vary as a function of the perceptual load of a task for instance.

Other researchers have argued for a variable threshold level according to the task demands. Houghton & Tipper (1994) for example, argued that responses are based on a variable rather than absolute levels of activation. According to this type of model, a response is based on the first stimulus representation to become sufficiently more activated than any other stimulus representation, where sufficiently refers to a variable threshold difference. Similarly, Barber & O'Leary (1997) suggested that the signal-to-noise ratio might play a part in response execution and suggested that response execution might be based on the activation of a response node exceeding the accumulated background activation of all other nodes.

The AASD model also rejects the continuous flow model notion of mutual inhibition as being the source of response slowing for incompatible flanker trials. To recap, the continuous flow model explains response slowing for trials with incompatible flankers in terms of the mutual inhibition of both the correct and incorrect responses. That is, when there is response competition (more than one response channel is activated due to the presence of incompatible flanker properties,) both response channels are inhibited from executing a response. The AASD model on the other hand suggests that a response is made on the basis of sufficient certainty that the most activated response is the correct response. This notion of response execution borrows concepts put forward in signal detection theory (SDT) in terms of a decision being based on the weight of evidence in favour of a response and there being some uncertainty.

3.3 Strength of Target Activation

The AASD model assumes that each individual stimulus is processed in parallel and that the activation generated by the compatibility properties of each stimulus will prime the corresponding response channel. Thus, the activation from each stimulus will be additive in that activations generated from each stimulus accumulates within the corresponding response channel. The greater the number of compatible properties there are in a stimulus array, the more the accumulated activation strength there will be in the correct response channel. Conversely, the more incompatible properties there are in a stimulus array, the higher the accumulated activation strength will be in the incorrect response channel.

A problem arises however, when we look at the level of accumulated activation in response channels for incompatible flanker arrays. In the incompatible flanker arrays, the number of incompatible properties outweigh the number of compatible properties (there are usually at least 2 or more flankers presented with 1 target). Thus, the activation accumulated within the incorrect response channel would exceed that accumulated within the correct response channel, and yet, we know that the correct response is made a majority of the time.

To get round this problem, it is assumed that the target generates a stronger activation than any individual flanker. As mentioned before, other theorists have proposed that the activation strength of the target might be enhanced compared to

other stimuli (Cohen, Servan-Schreiber & McClelland 1992; Eriksen & Schultz 1979; Cohen & Shoup 1997). Perhaps activation might also be enhanced by focused as opposed to automatic attention (see Eriksen, Webb & Fournier 1990 for a distinction between focused and automatic modes of attention). Cohen, Dunbar & McClelland (1990) also argued along similar lines with the idea that information that is the focus of attention is processed to a greater degree than information that is not the focus of attention.

Later, predictions for the order of the means for compatibility conditions are made on the basis that the target generates a stronger activation than that of any individual flanker. The target is given an arbitrary strength of activation that is calculated as the number of flankers +1. This is to ensure that activation generated by the flankers should not outweigh that generated by the target. However, it is thought that in some instances the activation in the incorrect response channel does outweigh that in the correct response channel because we know that errors are sometimes made. Possible reasons why the activation in the incorrect response channel might exceed that in the correct response channel are given later in section 3.5 (how the AASD model explains patterns of errors).

3.4 Processing Time and Accumulation of Activation strength Difference

We know that the identity of a stimulus is not immediately available but is derived through stimulus evaluation processing. That is, the identity of a stimulus is not

known immediately but is gradually derived through the gathering of information from stimulus evaluation processing which examines the properties/features of a stimulus and information about the stimulus features are pooled to eventually arrive at the stimulus identity (see McClelland's Cascade model 1979 for instance). As time progresses, so does the stimulus evaluation as it approaches the completion of the identity of a stimulus.

According to the continuous flow model and therefore the AASD model, activation is generated throughout stimulus evaluation and is passed on concurrently and simultaneously to the corresponding response channel. It is thought therefore that as time progresses, the amount of activation in the response channel increases. Because the AASD model assumes that the response channel with the strongest activation will be the one that executes a response, the certainty of making a correct response can be described in terms of the *accumulated* activation strength difference between competing response channels.

There is an ongoing debate as to the grain size of information (activation) that is passed onto the corresponding response channels as stimulus evaluation proceeds. At one end of the extreme are the strict continuous flow theorists who argue that the smallest possible amount of information (activation) is passed on as it becomes available. At the other end of the extreme are the traditional discrete stage theorists who argue that only information regarding the completed identity of the target

(largest grain size of information) is passed on to prepare a response and that the partial information derived from stimulus evaluation should therefore, have no role in preparing a response. However, we know from flanker task studies that partial information about a stimulus identity can prepare a response (shown by the observed compatibility effect for flankers that have physical similarity to possible target stimuli).

It is possible to argue for a hybrid model of discrete stage and continuous flow theories, if one assumes that partial information about a stimulus does prepare/prime a response but a final response execution decision is made on the basis of complete information regarding the identity of the stimulus. However, if this is the case, then it is hard to explain how errors in responding are made in the flanker task unless they are due to a faulty S-R pairing.

The AASD model assumes that as the time of processing increases, so does the activation accumulated within the response channels. It is assumed that the activation generated by stimuli increase in terms of a logarithmic function. Therefore, because the target is the focus of attention it is assumed that as time increases so does the activation strength difference in favour of the correct response channel. Thus, as time (T) increases, so does the certainty that the most activated response is the correct response. Put another way, the difference between the accumulated activation strengths in competing response channels will increase as a function of the stimulus

evaluation processing reaching completion. This is in line with the view of Grice, Canham, & Schafer (1982) who proposed that the associative strength leading to a response grows as a continuous function of the time after stimulus presentation.

The certainty that the most activated response is the correct response can be calculated by a simple subtraction of the strength of activation accumulated in the correct response channel from the strength of activation accumulated in the incorrect response channel for any point in time (T) throughout processing. It is thought that this certainty that the most activated response is the correct response is the mechanism behind the pattern of errors observed in the flanker task (see section 3.6 later on how the AASD model explains patterns of errors).

The certainty that the most activated response is the correct response will vary as a function of the ratio of compatible to incompatible flanker properties within a stimulus array. Imagine, for instance, a target flanked by 4 stimuli. If the flankers were all incompatible, then there would be a relatively large amount of activation given to the incorrect response channel. This would reduce the difference in activation strength because the activation accumulating within the incorrect response channel will be nearing the activation in the correct response channel with every additional incompatible flanker. On the other hand, if there were only 1 incompatible flanker and 3 compatible flankers, the activation generated by the incompatible flanker would be counteracted by the activation generated from one of the

compatible flankers. Thus, the certainty of making the correct response is mediated by the ratio of compatible to incompatible flanker properties within a stimulus array.

It is important to point out that the AASD model predicts that it is the ratio of compatible to incompatible flankers within an array that mediates the certainty of making the correct response, and not the number of compatible and incompatible flankers per se. Again, this idea borrows concepts from SDT in that the certainty of making a correct response is related to the signal to noise ratio (noise here would refer to the incompatible flanker properties). Furthermore, the AASD model is similar to SDT in that it accounts for the patterns of errors in responding in terms of the probability that the activation in an incorrect response channel being stronger than that in the correct response channel and by incorporating the idea of random variability (which may be variations in accumulated activation strengths – suggestions for the origins of these variations are given in section 3.5 below).

Figure 2 below depicts the accumulation of activation in response channels over time. Imagine that A is the strength of activation accumulated in a response channel and B is the activation strength in a competing response channel, as T increases the difference between A and B is also likely to increase as a function of the evidence (activation) accumulated from stimulus evaluation processing. Thus, as T increases so does the certainty (C) that the most activated response channel is the correct response channel.

We know then, that at a given point in time throughout processing (T), the certainty that the most activated response is indeed the correct response equates to the difference in accumulated activation strengths between the competing response channels. Thus, at T, $C = A - B$.

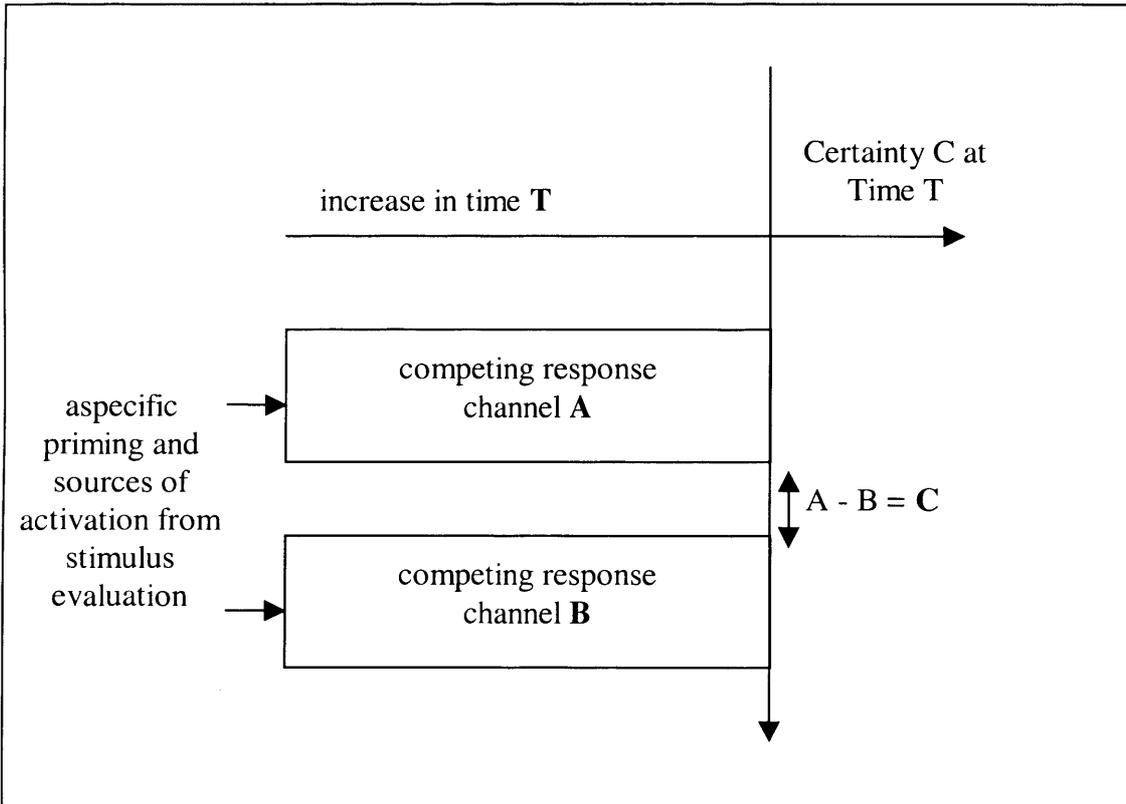


Figure 2. The Accumulated Activation Strength Difference Model

It is assumed that a response is made when the accumulated activation strength difference between the competing response channels reaches a sufficient amount of certainty of making the correct response.

3.5 How the AASD Model Explains Patterns of Errors in Responding

It is thought that for some cases the activation within the incorrect response channel is higher than that in the correct response channel, and in such cases, an error is made. As yet we are unsure what may be responsible for increasing the activation in the incorrect response channel but there are a number of possible reasons. We have seen that merely anticipating a response (see section 1.10) and also that task irrelevant information that can be associated with a response (see section 1.9 and 1.13) can also prime a response. It is also possible that a participant accidentally fixates a flanker rather than a target and that this might lead to an increase in the activation in the incorrect response channel. Thus, there are a number of factors that might contribute to increasing the activation in the incorrect response channel that are not task specific. Signal detection and other theories have attributed random variability to account for errors. Random Walk models for instance, explain fast errors in terms of variability in the starting point of a walk (see Laming 1968 and Ratcliffe 1981).

The likelihood that the activation in the incorrect response channel will exceed that in the correct response channel (and therefore that an error will be made) differs according to the difference in accumulated activation strengths between the incorrect and correct response. The probability of making an error therefore, can be seen as a function of the difference in accumulated activation strength difference at any given point in time. That is, there is a greater likelihood of making an error when there is

already a higher ratio of incompatible to compatible flanker properties within a stimulus display. This is because the random activation that may lead to an increase in activation in the incorrect response channel (due to possible reasons mentioned earlier) is more likely to push the activation in the incorrect response channel above that in the correct response channel when the accumulated activation strength difference is small. Thus, there is a higher probability of making an error when there is a higher ratio of incompatible to compatible flanker properties within a stimulus array.

3.6 How the AASD Model Explains the Compatibility Effect

The AASD model explains the compatibility effect in terms of both facilitation due to compatible flanker properties and response slowing due to incompatible flanker properties. This is consistent with Rösler & Finger's (1993) psychophysiological analysis of response channel activation for the flanker task which found that incompatible flankers had inhibitory effects on responding and increased the likelihood of errors, whilst compatible flankers facilitated responding and decreased the likelihood of errors. However, the AASD model suggests that the facilitative effects of compatible flankers are only observed under conditions where there is also response competition and this is discussed in more depth below.

3.6.1 Inhibition from Incompatible Flanker Properties

The AASD model can explain the compatibility effect in terms of the presence of incompatible information increasing the activation in the incorrect response channel. This reduces the difference in activation strength between competing response channels because each additional incompatible flanker property increases the activation in the incorrect response channel, which results in the activation strength in the incorrect response channel nearing that in the correct response. Some theorists refer to the slowing of RT by incompatible flanker properties as interference or inhibition. The term 'response slowing' is preferred here because the slowing of RT observed with incompatible flankers is not thought to be due to the incompatible information interfering with compatible information or inhibiting responding as such.

An incompatible flanker property within an array can be counteracted by a compatible flanker property within an array because each would provide an equal amount of activation (given that the flanker dimension concerned is the same - see the later section on more than one stimulus dimension) to the correct and incorrect response channels respectively. Thus, neither would add anything to the activation strength difference. When there is a combination of compatible and incompatible flanker properties within a stimulus array, it is the ratio of incompatible to compatible instances within a stimulus array that affects the activation strength difference rather than the number of incompatible or compatible instances per se. Thus, the more the residual incompatible instances in a stimulus array, the smaller the difference in the

activation strengths between the competing response channels will be. This would result in further processing being required in order to achieve sufficient certainty/difference that the most activated response is indeed the correct response.

The AASD model can therefore, explain the RT patterns for trials that contain incompatible flanker properties. The more the residual incompatible flanker properties there are, the lower the initial activation strength difference (and therefore C) and the longer it would take to reach sufficient certainty that the most activated response is the correct response. The AASD model predicts that the ordering of the RTs for conditions can be calculated by a simple subtraction of the number of incompatible flanker properties to compatible flanker properties within that condition.

So far, no flanker task studies have assessed the ratio of compatible to incompatible flankers for one stimulus dimension. The present research predicts that the ratio of compatible to incompatible instances within an array, mediates the extent of the compatibility effect, with an increase in RTs as the number of residual incompatible flanker properties increases. It is predicted that the higher the ratio of incompatible flanker properties to compatible flanker properties there are within a stimulus array, the greater the response slowing will be. The AASD model also makes predictions based on the extent that responding is facilitated by compatible flanker properties

3.6.2 Facilitation from Compatible Flanker Properties

The AASD model predicts that under certain conditions, compatible flanker properties facilitate RT. It is assumed that when a stimulus array contains information that gives activation to a competing response channel (the incorrect response channel for instance or maybe even a neutral response channel), then compatible flankers would serve to facilitate RT. Evidence for this claim is generated by the redundancy gain observed in the letter detection task studies (described in section 1.5). For flanker tasks however, no facilitation has been found under conditions when no competing response channel is activated. It seems therefore, that in order for the compatible flanker properties to be facilitative, a stimulus array also has to contain noise stimuli (incompatible flanker properties or neutral flankers).

The AASD model can account for this inconsistency in the following way. When there are no neutral or incompatible flanker properties (as in compatible or target alone trials), only the correct response channel receives activation from the stimulus evaluation processing. Because only the correct response channel is activated, the certainty that the most activated response is the correct response is immediate. Thus, performance for compatible and target alone trials would be at ceiling level. This suggests that the RT would not differ between target alone trials and compatible flanker trials. For the same reason, there is not expected to be any difference in performance between compatible conditions that differ in the number of flankers that they present.

However, we know that the number of compatible flankers can have an additive effect in terms of the facilitation in responding when an array contains neutral flankers. Letter detection tasks for instance, present repetitions of the target within arrays that contain noise stimulus (neutral stimulus, see footnote¹) and the redundancy gain increases as a function of the number of identical targets presented within the stimulus array. This redundancy gain was explained in terms of the repetitions of the targets taking the possible place of noise flankers and the facilitation due to repetitions of the target were seen as merely noise reduction (see again section 1.5).

Although the AASD model has not attempted to account for neutral flankers, it also predicts that compatible flanker properties will facilitate responding when a stimulus array also contains incompatible or neutral flanker properties. The AASD model however, suggests a slightly different reason why redundancy gain (facilitation due to compatible flanker properties) is observed. It is suggested that compatible flanker properties counteract the activation generated by incompatible flankers. That is, compatible instances within stimulus arrays that also contain incompatible instances serve to reduce the slowing effects of incompatible flanker properties.

¹ Note: Because neutral flankers produce an intermediate compatibility effect it is thought that they activate some competing response channel. However it is not known whether they in fact activate the incorrect response channel in some way or whether they activate a non-specific response channel. One of the limitations of the AASD model is that it does not attempt to account for the effects of neutral flankers.

The AASD model therefore, can account for the redundancy gain effect being absent in the flanker task but present in the letter detection tasks. Flanker task studies, for instance, examined redundancy by comparing target alone trials to compatible flanker trials. Under both conditions there is no competing response channel activation and therefore, the certainty that the most activated response is the correct response is immediate in both cases. There would be no need for the stimulus evaluation to continue further than the first instance of activation because it provides immediate sufficient certainty that the most activated (and only) response channel is the correct response. Letter detection tasks on the other hand have shown that there is redundancy gain when a stimulus array contains noise flankers. The AASD model is able to account for these inconsistencies by suggesting that compatible flanker properties facilitate responding when there is response competition.

So far, the facilitative and response slowing effects have been described using only one flanker dimension. Is it possible that the effects from different flanker dimensions on responding might interact. Put another way, can the slowing generated by an incompatible colour be counteracted by a compatible shape?

3.7 More than One Stimulus Dimension

It is assumed that the activation generated from any relevant dimension i.e. colour, shape etc. all contribute to the accumulated activation in the corresponding response channel. If a response is based on either the colour or shape, or both the colour and

shape of a target, then it is possible to have a flanker that has both compatible and incompatible properties. A flanker that has a compatible colour and an incompatible shape will give activation to both the correct and incorrect response channels respectively. However, there is some evidence that different dimensions/features of a stimulus are processed at a different rate or they generate different activation strengths. Henik, Ro, Merrill, Rafal and Safadi (1999) for example, found differences in the propensities of colour and word information to affect responding. Furthermore, Fournier, Eriksen & Bowd (1998) assumed that target features that are relatively easy to discriminate (e.g. colour) would on average prime the corresponding response before features that are more easy to discriminate (such as the size of the stimulus).

It has also been suggested that stimuli that have stronger associated S-R mappings or have greater utility in making a response, generate faster and/or stronger activations than stimuli that have weaker associated S-R mappings. The current research does not focus on S-R compatibility, but the possibility that one dimension might have a stronger associated S-R mapping and therefore a greater propensity to prime a response may cause problems when assessing more than one stimulus dimension.

The AASD model will be assessed primarily to account for the compatibility effect with one stimulus dimension, although it offers scope to account for more than one dimension. In order to assess whether the AASD model can accurately account for the patterns of RT and errors for more than one stimulus dimension, further research

would be required to determine any differences in processing between the dimensions. If, for instance, colour has a faster processing speed than shape, then one would expect colour to have a greater propensity to elicit the compatibility effect. This is because colour information would reach the response channels quicker than shape information and would be able to prepare responses quicker than shape information (more about this later). Also, because the AASD model suggests that information from any dimension can prepare a response, it is assumed that there will be an additive effect of the activation from different stimulus dimensions on RT providing that the different stimulus dimension have equal processing speeds and activation strengths.

Whether an incompatible shape and a compatible colour could counteract each other depends on the strength and/or speed of activation that each dimension generates. If the activation of colour and shape are equal, then compatible and incompatible instances across shape and colour dimensions should counteract each other. If they are not equal, then we may expect to see a crossover effect, where the residual activation would be predominant in eliciting the compatibility effect.

3.8 Summary

The AASD model assumes that each stimulus within an array generates its own activation and that these individual activations are pooled within the corresponding response channels. Because the AASD model assumes that response execution is

based on sufficient difference in accumulated activation strengths (certainty that the greatest activated response channel is the correct response) the model can explain both the patterns of RT and errors in responding.

The AASD enables a number of predictions to be made about the ordering of the means according to the ratio of compatible flanker properties to incompatible flanker properties. The RTs and erroneous responses are predicted to increase as the ratio of incompatible to compatible flanker properties increase. Furthermore, compatible flanker properties are only thought to facilitate responding when there is response competition

In order for the AASD model to work, it is assumed that the activation strength of the target is increased and the activations generated by stimuli increase in terms of a logarithmic function over time. The level of activation assigned to the target is calculated as the number of flankers +1 because this will ensure that the activation strength in the correct response channel is usually greater than that in the incorrect response channel. Because the level of activation strength assigned the target is arbitrary, no predictions are made in terms of whether there would be an interaction between the number of flankers and the compatibility condition. It is not possible for instance to suggest that an incompatible flanker array with 6 flankers will produce longer RTs than an incompatible flanker condition with 4 flankers because the level

of activation generated by the target might vary as the number of flankers vary (or as the perceptual load of the task varies).

Chapter 4

Testing the AASD Model

4.1 Predictions for the Ordering of the Mean RTs of the Compatibility Conditions

Because compatible flankers are thought to facilitate responding (when there are also incompatible and/or neutral flankers within a stimulus array) and incompatible flankers are thought to inhibit responding, the effects of compatible and incompatible flankers are predicted to cancel each other out (given that they have the same activation strengths and speeds). To test this prediction, Experiment 1 was conducted using a typical flanker task with the inclusion of conditions that combined flanker types (the compatibility of the flankers) within a stimulus array. This was to examine whether RTs are influenced by mixed flanker conditions. It was thought that conditions that contained purely incompatible flankers would generate slower RTs and more errors than a compatibility condition that contained a mixture of incompatible and compatible flankers for arrays that have the same number of flankers.

Because the AASD model predicts that there will be no facilitation due to compatible flankers if there is no response competition, Experiment 1 varied the number of flankers within the stimulus array. There were either 2, 4 or 6 flankers for each compatibility condition. It was expected that there would be no difference in RT

between compatible conditions with 2, 4 or 6 flankers because performance should be at a ceiling level for all three conditions, due to there being no response competition. Thus, there should be no difference in RTs for compatible conditions with 2, 4 or 6 flankers.

Some might argue that performance might be expected to decline when there are more flankers compared to fewer flankers within a stimulus array due to the additional processing resources taken by additional flankers. However, there is evidence to suggest that when stimuli are presented in a linear array, the number of flankers presented within that array do not tend to influence performance (Eriksen & Eriksen 1974) as a similar compatibility effect seems to be obtained when there are one or two flankers either side of the target (Eriksen & Schultz 1979, Coles, Gratton, Bashore, Eriksen & Donchin 1986). Such studies, however, did not look at the ratio of compatible to incompatible flankers within a stimulus array and the ratio was the same for when there was one or two flankers either side of the target. However, these studies did find that the distance from the flankers to the targets did influence the flankers' affect on responding with less effect for flanker at further eccentricities from the target.

The ordering of the means for the compatibility conditions can be numerically calculated by assigning an activation strength value to a flanker and the target and then working out the difference in the activation strength that will be received by the

correct and incorrect response channels respectively. To calculate the predictions for the ordering of means for the compatibility conditions, the activation strength assigned to an individual flanker is 1. However, an incompatible flanker would reduce the activation strength difference between the correct and incorrect response channels by 1 thus the value of -1 is assigned to an incompatible flanker. It is predicted that the larger the difference between the activation strength received by the correct and incorrect response channel, the faster the RTs will be.

The activation strength generated by the target is assumed to be the number of flankers (the maximum possible number of incompatible flankers) plus 1. For 2 flanker conditions, it is assumed that the activation strength generated by the target is 3 times the strength of an individual flanker. Likewise for the 4 and 6 flanker conditions, the activation strength assigned to the target will be 5 and 7 times that of an individual flanker respectively. This is to ensure that the correct response is made a majority of the time.

It would be possible to assume that the activation strength allocated to the target is 7 for all the number of flanker conditions. In this case, the activation strength of the target will still be stronger than the summation of activation generated by all the flankers under all compatibility conditions. However, the AASD model does not predict whether the activation strength of the target is influenced by the compatibility condition and/or the number of flankers condition or whether indeed its' value is

static across all these conditions. It could be, for instance, that the activation strength afforded the target is manipulated according to the perceptual load of the task and is therefore variable and in line with the zoom lens metaphor of attention. However, little is known as yet as to how attentional or processing resources are allocated. Thus, it is thought that the dilemma of whether the activation strength of the target is static or variable is an argument based in theory relating to the allocation of attentional resources and is beyond the scope of this research.

Because the activation strength assigned the target is arbitrary, the AASD model does not make predictions concerning any possible interactions between the number of flankers and the compatibility conditions with the exception of the compatible condition mentioned above. It is thought that it might be fair to assess whether facilitation occurs between the compatible conditions for 2, 4 and 6 flankers because the compatible condition is unique in that the certainty that the most activated response is actually the correct response is instantaneous (due to there being no alternative response channel activation).

The calculations for the predictions of the ordering of mean RTs for the compatible condition, the incompatible condition and a mixed compatible and incompatible condition (an equal number of compatible and incompatible flankers) are shown below in Tables 1 - 3. The calculations are given in separate blocks according to the

number of flankers because no predictions are made in terms of a possible interaction between the number of flanker conditions and the compatibility conditions.

Condition	Stimulus	Addition	Difference
compatible	>>>	1 + 3 + 1	5
mixed	<>>	-1 + 3 + 1	3
incompatible	<><	-1 + 3 + -1	1

Table 1. Calculations for the ordering of the means for 2 flankers (target activation strength 3 times that of an individual flanker)

Condition	Stimulus	Addition	Difference
compatible	>>>>>	1 + 1 + 5 + 1 + 1	9
mixed	<<>>>	-1 + -1 + 5 + 1 + 1	5
incompatible	<<><<	-1 + -1 + 5 + -1 + -1	1

Table 2. Calculations for the ordering of the means for 4 flankers (target activation strength 5 times that of an individual flanker)

Condition	Stimulus	Addition	Difference
compatible	>>>>>>	1 + 1 + 1 + 7 + 1 + 1 + 1	13
mixed	<<<>>>>	-1 + -1 + -1 + 7 + 1 + 1 + 1	7
incompatible	<<<><<<	-1 + -1 + -1 + 7 + -1 + -1 + -1	1

Table 3. Calculations for the ordering of the means for 6 flankers (target activation strength 7 times that of an individual flanker)

The difference in activation strength between the correct and incorrect response channels is largest in the compatible condition followed by the mixed compatible and incompatible condition and smallest for the incompatible condition and this is the same for when there are 2, 4 and 6 flankers. This shows that the compatible condition is expected to generate faster RTs compared to the mixed condition and

the mixed condition will generate faster RTs compared to the incompatible condition.

That the differences between the compatibility conditions increases as the number of flankers increases is a by-product of the arbitrary activation strength assigned to the target and should not be taken to suggest an interaction. What is important is that the predictions for the ordering of the mean RTs for each compatibility condition is consistent across the number of flankers conditions.

Because the AASD model is only concerned with the difference between the correct and incorrect response channels, no predictions are made for the neutral condition. However, a neutral condition was included in the Experiment 1 to serve as a gauge to compare the patterns of responding found here to previous experiments that show that neutral flankers have an intermediate affect on RT in the flanker task. Based on previous findings then, it is predicted that the neutral condition will generate faster RTs than the incompatible condition and slower RTs than the compatible condition. In addition, Experiment 1 also presented a neutral and compatible flanker condition and a neutral and incompatible flanker condition (equal numbers of flanker types in each condition). This was merely out of interest to see if any discernable pattern emerges.

4.2 Predictions for the Percentages of Errors Generated.

It is expected that the pattern of errors will mirror the pattern observed for the RT data because it is assumed that the probability of making an error will increase as the difference in accumulated activation strength decreases.

4.3 Experiment 1:Method

4.3.1 Participants

84 undergraduates students at Aston University took part in this experiment and received either 30min research credit (8 hours of research credit are a prerequisite for the completion of the 1st year Psychology course) or a chocolate bar and a soft drink was offered to those that did not need to collect research credits.

4.3.2 Apparatus and Stimuli

The stimuli were presented on a Macintosh IIsi and the trials were generated using the Superlab package version 1.4, developed by Cedrus Corporation.

4.3.3 Design

This experiment required a left or right button press (both equidistant from a central point) on a keyboard (the C or M keys respectively) to a target shape that was either a filled square or a filled cross. The response association was counter-balanced between individuals with half the participants being required to press C for a cross and M for a square and the other half being required to press an C for a square and

M for the cross. The flankers were made up of combinations of compatible, incompatible and neutral flankers. A triangle was chosen for the neutral flankers due to its dissimilarity with both the cross and the square. There were 6 possible compatibility conditions formed by the flankers in relation to the target: all neutral; all compatible; all incompatible; compatible and neutral; incompatible and neutral; and compatible and incompatible. Each stimulus subtended a visual angle of $0.76^\circ \times 0.76^\circ$ at a viewing distance of 75cm from the screen. The contour-to-contour distance between the stimuli also subtended 0.76° of a visual angle.

The number of flankers was also varied. There were either 2, 4 or 6 flankers presented with the target with an equal number of flankers presented either side of the target.

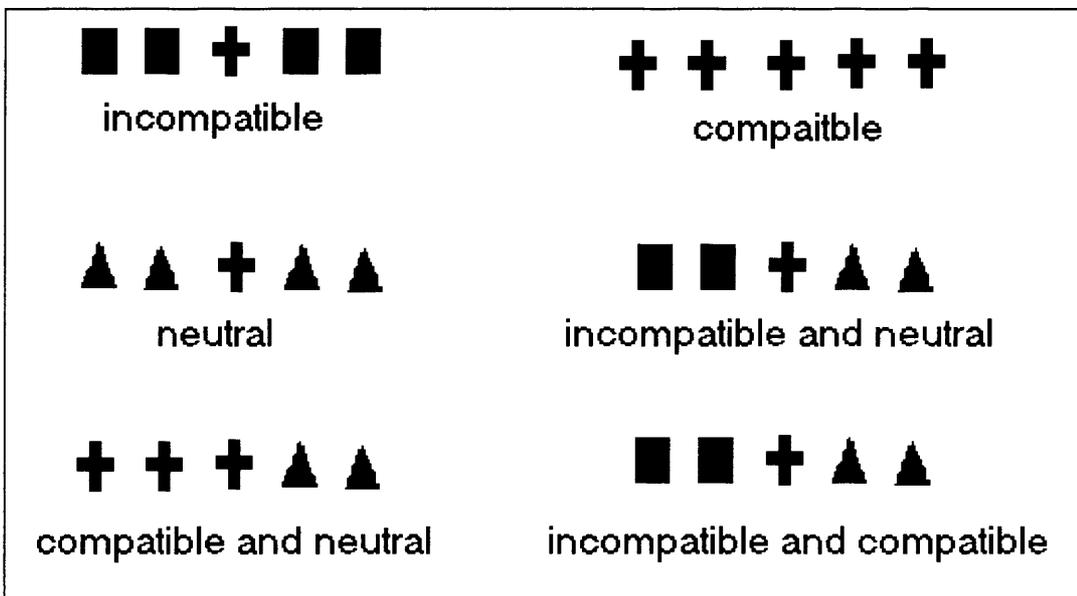


Figure 3. Examples of the compatibility conditions with 4 flankers.

When there was more than one flanker either side of the target, the adjacent flankers were always identical. Figure 3 above shows the compatibility conditions with 4 flankers.

Arranging the flankers in a linear array along the horizontal plane allows for examination of whether the spatial separation between the flankers and the target mediate the extent of the compatibility effect. According to the Spotlight metaphor of attention, providing all of the flankers fall within the spotlight of visual attention, they should all have the same propensity to affect responding and therefore we might expect the activations generated by each flankers to be additive. Thus, we would expect longer RTs for conditions that have 6 incompatible flankers compared to 2 incompatible flankers for instance. If however, the outer four flankers fall outside the spotlight of visual attention, we would expect to see the same RTs for the compatibility conditions regardless of whether there are 4, or 6 incompatible flankers as there would be no incremental cost of responding associated with the outer flankers. In this case there should be differences across the number of flankers conditions.

It is less easy to predict how the number of flankers and the compatibility conditions would interact for the neutral and compatible conditions compared to the compatible condition because as yet we are unable to conclude whether compatible flankers

facilitate responding under conditions of no response competition and no predictions are made in terms of how neutral flankers affect responding.

If one adheres to the gradient metaphor of attention then one would predict diminishing returns in relation to the number of flankers and the compatibility conditions. For the incompatible flanker conditions for instance we would expect that there would be more response slowing for 6 flanker conditions compared to 4 flanker conditions and 2 flanker conditions (providing the size of the spotlight beam of attention will encompass all flankers). However, the response slowing across the flanker conditions is not predicted to be a linear function as the activation generated from the outer flankers should be degraded in relation to that of the flankers closer to the target.

In the case that size of the attention spotlight is changeable as illustrated by applying the zoom lens metaphor to describe visual attention, then we might expect to see a number of different effects. Whether some or all of the flankers fall within the visual attention spotlight beam would depend upon the resources taken up in processing the task (the attention paid to the target for example, which, might be manipulated in terms of how hard it is to map the target onto the response amongst other things). Furthermore, that the size of the attentional beam may vary as a function of the perceptual load demands of the task (see Lavie and colleagues theory of perceptual load in section 1.15) further complicates matters. Presumably the perceptual load of

the task is harder for incompatible flanker trials compared to compatible flankers trials as more resources may be required to overcome the competing activations in order to achieve sufficient certainty of making a correct response. Thus, we might expect to see differences in terms of the propensities of outer flankers to affect responding based on the compatibility condition.

Because of the differences in terms of the size or quality of the visual attentional field and because the activation strength of the target is assigned an arbitrary value, which, may, or may not be variable across the number of flankers and/or compatibility conditions, no predictions are made in terms any interactions between these variables. However, as mentioned earlier the differences between the compatible conditions with 2, 4 and 6 flankers will be examined with the above complications in mind to see if any obvious pattern in terms of response facilitation occurs. It is thought that the compatible condition is unique in that the certainty of making a correct response should be immediate due to their being no response competition. Considerations of perceptual load should therefore be less of a problem.

For simplicity, the experiment was divided into three parts. Each part comprised the 6 compatibility conditions with one of the three levels of number of flankers. Therefore, there were 18 conditions in all:

Part 1

- 2 Flankers/Compatible,
- 2 Flankers/Incompatible,
- 2 Flankers/ Neutral,
- 2 Flankers/Compatible and Neutral,
- 2 Flankers/Incompatible and Neutral,
- 2 Flankers/Compatible and Incompatible,

Part 2

- 4 Flankers/Compatible,
- 4 Flankers/Incompatible,
- 4 Flankers/Neutral,
- 4 Flankers/Compatible and Neutral,
- 4 Flankers/Incompatible and Neutral,
- 4 Flankers/Compatible and Incompatible,

Part 3

- 6 Flankers/Compatible,
- 6 Flankers/Incompatible,
- 6 Flankers/neutral,
- 6 Flankers/Compatible and Neutral,
- 6 Flankers/Incompatible and Neutral,
- 6 Flankers/Compatible and Incompatible,

Each part required the participant to perform a practice block of 36 trials followed by an experimental block of 72 trials. All the trials were randomised before presentation and there were an equal number of the compatibility conditions in the practice blocks and experimental blocks to avoid expectancy effects. The order in which the parts of the experiment were conducted was counter-balanced.

4.3.4 Procedure

The participants were presented with the instructions on the computer screen (see Appendices for instructions). After the instructions had been read, the participants were prompted to press any key to commence the first practice block of trials. For

each trial a small-unfilled circle in the centre of the screen served as a fixation point. The participants were instructed to gaze at the circle as this is where the target would appear. The circle disappeared after 1000ms and was replaced by the target and flankers. Participants were instructed to make a response based on the identity of the target and to ignore the flankers. A cut-off time of 3000ms after the presentation of the stimulus was imposed. If the participants had not responded within this time the next trial was automatically presented. Participants were required to respond to the target as quickly as possible whilst also being accurate.

4.4 Experiment 1: Results

4.4.1 Analysis of Reaction Times

Boxplots show that there were a number of outliers in the RT data. An outlier was determined by box plots using SPSS version 8. Outliers are defined as values that are more than 1.5 box lengths above or below the box. The parameters of the box plot itself encompass the values between 25th and 75th percentiles (upper and lower quartiles). There were 2.84% of outliers in this data. The outliers were removed from the analysis and the empty cells were replaced with the maximum value for that condition which was not an outlier.

Compatibility Condition	No. of Flankers	Mean RT	SD
Compatible/Neutral	2	407	62.6
Compatible	2	408	63.8
Incompatible/Neutral	2	408	59.8
Neutral	2	409	66.5
Neutral	4	410	62.6
Compatible	4	411	56.6
Incompatible/Neutral	4	413	63.2
Incompatible	4	413	57.4
Incompatible	2	413	64.8
Mixed	2	414	62.1
Compatible/Neutral	4	415	65.7
Mixed	4	417	63.4
Compatible	6	418	65.4
Compatible/Neutral	6	422	72.0
Incompatible/Neutral	6	424	63.9
Mixed	6	424	66.8
Incompatible	6	425	64.0
Neutral	6	428	76.2

Table 4. Mean RTs (ms) in ascending order for all conditions

A 6 (compatibility condition) X 3 (number of flankers) Repeated Measures ANOVA was conducted. A main effect of number of flankers [$F(2, 166) = 5.45$; $ms_{error} = 745.17$; $p=0.005$] was found. This is not consistent with previous studies that showed that the number of flankers does not influence performance when the flankers are arranged in a linear array. These results instead suggest that there is cost of processing more information. The means for the number of flanker conditions are given in the table below.

No of Flankers	Mean (ms)	SD
2	410	63.1
4	413	61.3
6	424	67.9

Table 5. Means in ascending order for the flanker conditions

Tukey tests were performed to see where the significant differences lie. The results are given in the table below and show that the 6 flanker condition generated significantly longer RTs than both the 2 and 4 flanker conditions.

	2 flankers	4 flankers
4 flankers	q = 1.05 p > 0.05	*
6 flankers	q = 4.47 p < 0.01	q = 3.41 p < 0.05

Table 6. Differences between the compatibility conditions

That only 6 flanker conditions generate longer RTs than 4 and 2 flanker conditions suggests that there is no significant difference between the 2 and 4 flanker conditions and that the incremental cost in performance associated with adding two flankers is not uniform within a stimulus array. This finding is not consistent with the gradient

metaphor of attention as this would predict that if there would be a cost of having two additional flankers, the cost would be more profound between the 2 and 4 flanker conditions rather than between the 6 flanker condition and the 2 and 4 flanker conditions. This is because the propensity of flankers to affect responding should decrease at further eccentricities from the target. This finding is novel and the possible cause of this effect is not clear.

The results are inconsistent with previous studies in that no main effect of compatibility condition [$F(5, 415) = 1.68$; $ms_{error} = 4706.69$; $p > 0.05$] was found. Furthermore, no significant interaction between compatibility condition and number of flankers [$F(10, 830) = 0.67$; $ms_{error} = 839.45$; $p > 0.05$] was found either.

It seems that there was some methodological flaw in Experiment 1 because the robust compatibility effect was not observed and the range of RTs is quite small (21ms compared to previously reported compatibility effects of around 40ms). It was thought that the participants might have completed too fewer trials in order to adequately learn the target and response mapping. If the participants had not generated strong associations between the target and its associated response then it is unlikely that the compatibility effect would be observed.

4.4.2 Comparison of the Compatible Condition with 2, 4 and 6 Flankers

It was not possible to compare the compatible condition across the number of flankers to determine whether compatible flankers have a facilitative and additive effect on RT because the results showed that the more flankers there were, the slower RTs were per se. Indeed, the ordering of the means for the compatible conditions found that 6 compatible flankers produced longer RTs than compatible conditions with 4 or 2 flankers which suggests that there is some cost of processing more stimuli compared to fewer stimuli. Furthermore, there is no interaction between the number of flankers and the compatibility conditions.

4.4.3 Analysis of Errors

The number of errors generated by the participants was too small to be analysed (less than 1 %). It may have been that the participants were putting a lot of attention in to formulating a response. It may have been the case that the participants had not developed strong S-R associations due to them having to perform a small number of trials. It could be therefore, that there was a trade-off between speed and accuracy that culminated in favour of correct responding.

4.4.4 Discussion

The results indicated that there is an additive effect of the number of flankers on RT. That is, the more flankers there are, the longer the RTs were in responding. However, post hoc analysis revealed that the difference between 4 and 2 flankers did

not reach statistical significance. For this reason, it was not possible to examine whether compatible flankers had a facilitative and additive affect on RT.

Furthermore, the compatibility effect was absent in this experiment and it is thought that this may be due to the participants only performing a few repetitions of each condition and were not sufficiently trained to associate the target and response mappings. Furthermore, there were too few errors recorded for statistical analysis. Experiment 2 therefore, used fewer participants but required them to conduct more trials.

4.5 Experiment 2: Method

This experiment was the same as the previous experiment although it attempted to reduce the SDs by increasing the number of trials that the participants were required to perform. It was thought that by increasing the number of trials, participants would have stronger S-R associations between the target and the response and this would improve performance.

4.5.1 Participants

12 undergraduates from Aston University took part in this experiment and received either 1-hour credit (again 8 hours worth of research credits are a prerequisite for the completion of the 1st year Psychology course) or a bar of chocolate and a soft drink for those that did not need to collect research credits.

4.5.2 Apparatus and Stimuli

The stimuli were presented on a Macintosh IIsi and the trials were generated using the Superlab package version 1.4, developed by Cedrus Corporation.

4.5.3 Design

The experimental design was identical to Experiment 1 with 2 exceptions:

- 1) Because of the failure of Experiment 1 to generate the compatibility effect, the design of this experiment was simplified by omitting the compatible and neutral condition and the incompatible and neutral condition. However, the

neutral condition was not omitted because previous research (see section 1.4) had found that the neutral condition has an intermediate effect on RT and it is therefore a useful gauge of the compatibility effect. The mixed compatible and incompatible flanker condition can now be called the mixed condition because it is the only condition that presents a combination of mixed flanker types (namely compatible and incompatible flankers).

- 2) Secondly, Experiment 2 used fewer participants and required them to conduct more trials than were required in Experiment 1. It may be that the participants did not complete enough trials in order for the S-R associations to be sufficiently learned. Thus, it is expected that increasing the number of trials will also decrease the RTs.

Again there were three parts to this experiment that are distinguished by the number of flankers that were presented (2, 4 and 6 as in Experiment 1). There were two practice blocks each with 32 trials (8 trials of each compatibility condition) and four experimental blocks each with 112 trials (28 trials of each compatibility condition) for each part. The stimuli were identical to those in Experiment 1 and again the trials were randomised per block. All other aspects of the design were identical to Experiment 1.

4.5.4 Procedure

The procedure was identical to that of Experiment 1. The participants were again presented with instructions on the computer screen. After the participants had read the instructions they were prompted to press any key to commence the first practice block of trials. A small-unfilled circle appeared in the centre of the screen and served as a fixation point. The participants were instructed to gaze at the circle, as this is where the target would appear. The circle was replaced by the target (and the adjacent flankers) 1000ms after its' onset. Participants were instructed to make a response (by pressing the 'C' or 'M' keys on a keyboard) based on the identity of the target and to ignore the flankers. A cut-off time of 3000ms after the presentation of the stimulus was imposed. If the participants had not responded within this time, the next trial was automatically presented. Participants were required to respond to the target as quickly as possible whilst also being accurate.

4.6 Experiment 2: Results

4.6.1 Analysis of Reaction Times

The means for Experiment 2 are given in Table 7 below, and are noticeably quicker than those in Experiment 1 (range 386-410 and range 407-428 respectively). The SDs are also noticeably reduced. This indicates that participants' performance improved with more trials and suggests that the participants developed stronger S-R associations. Again there were some outliers (2.87%). The outliers were defined and

treated consistently with Experiment 1 and were again replaced with the highest value for that condition that was not an outlier.

Compatibility Condition	No. of Flankers	Mean RT	SD
Compatible	4	386	32.1
Neutral	6	388	49.0
Compatible	2	389	46.4
Compatible	6	389	49.6
Incompatible	4	389	32.7
Incompatible	2	390	39.9
Neutral	2	390	44.4
Neutral	4	395	55.9
Incompatible	6	395	47.9
Mixed	2	395	43.1
Mixed	6	398	54.8
Mixed	4	410	50.1

Table 7. Mean RTs (ms) in ascending order for all conditions

At first glance, there does not seem to be any obvious pattern in the ordering of the means for the number of flanker conditions and, unlike Experiment 1, a 3 (number of flankers: 2, 4 or 6) X 4 (compatibility condition: compatible, neutral, incompatible, mixed) Repeated Measures ANOVA revealed that there was no significant main effect of number of flankers [$F(2, 22) = 0.15$; $m_{\text{error}} = 1322.78$ $p > 0.05$]. There are two differences between Experiment 1 and this experiment: the absence of the mixed incompatible and neutral flanker condition and the mixed compatible and neutral flanker conditions in Experiment 2, and the increased number of practice and experimental trials in Experiment 2. It seems unreasonable to suggest that the

number of flankers' effect found in Experiment 1 was manifest in the mixed incompatible and neutral flanker condition and/or the mixed compatible and neutral flanker condition. Rather, a more likely explanation is that absence of differences between the number of flanker conditions is due the increased number of trials.

The ordering of the means in terms of the compatibility condition is not consistent with the classic compatibility effect in all cases. Whilst for 2, 4 and 6 flanker conditions the compatible condition produced faster RTs than the incompatible condition, the neutral condition does not appear to have an intermediate effect on responding. Also, the difference between the compatible condition and the incompatible condition is very small (the largest difference is 6ms, which, is between the compatible and incompatible conditions with 4 flankers) compared to the differences reported in previous studies of around 40ms. Thus, the classic compatibility effect is only partially observed here. Furthermore, the mixed compatibility condition generated the longer RTs than the incompatible condition and this is consistent across 2, 4 and 6 flanker conditions. This is not consistent with the predictions made by the AASD model that predicts that the mixed condition would generate faster RTs than the incompatible condition.

The Repeated Measures ANOVA did, however, reveal a significant main effect of compatibility condition [$F(3, 33) = 6.91$; $ms_{error} = 165.59$ $p = 0.001$] and no

significant interaction between the number of flankers and the compatibility conditions [$F(6, 66) = 2.18; p > 0.05$] was found.

Compatibility condition	Mean (ms)	SD
Compatible	388	42.2
Neutral	391	48.6
Incompatible	391	39.5
Mixed	401	48.6

Table 8. Mean RTs (ms) in ascending order for the compatibility conditions

A series of Tukey tests were conducted to ascertain where the differences lie and the results can be seen in Table 9 below.

	Compatible	Neutral	Incompatible
Neutral	q = 1.28 p > 0.05	*	*
Incompatible	q = 1.54 p > 0.05	q = 0.26 p > 0.05	*
Mixed	q = 6.02 p < 0.01	q = 4.75 p < 0.05	q = 4.48 p < 0.05

Table 9. Differences between the compatibility conditions

The post hoc analyses show some surprising results. The mixed condition produced significantly longer RTs than all of the other compatibility conditions. This finding is not in line with the predictions of the AASD model that predicted that the

incompatible condition would generate the slowest RTs of all compatibility conditions.

It is clear that Experiment 2 also contained some flaws that may have prevented the compatibility effect from being observed. The reason for the unexpected results here is not clear, but it is thought that the quality of the stimuli might not be of a high enough standard to generate the compatibility effect. Previous flanker tasks studies used letters and or shapes that have intrinsic properties associated with a directional response (i.e. arrows) as stimuli rather than arbitrary shapes as used here.

4.6.2 Comparison of the Compatible Condition with 2, 4 and 6 Flankers

The means show that ordering of the compatible conditions is not consistent with the idea that compatible flankers have a facilitative effect on RT. This because the 4 flanker condition produced the quickest RTs followed by when there were 2 flankers and then the 6 flanker condition. Furthermore, there was no significant interaction between the number of flankers and the compatibility condition. This shows that there is no additive facilitation due to additional compatible flankers in the absence of incompatible (or neutral) flankers. This is as predicted by the AASD model although the AASD model also predicts that the mixed condition would produce faster RTs than incompatible flanker condition on the basis that compatible flankers have an additive and facilitative effect on RT when there are incompatible flankers within a stimulus array.

4.6.3 Analysis of the Errors

The percentages of errors made for each condition are given in Table 10 below.

There were 2.08% outliers in this data that were replaced with the highest value for that condition that was not an outlier.

Compatibility Condition	No. of Flankers	Mean %age	SD
Compatible	2	4.6	2.7
Neutral	6	5.1	3.4
Incompatible	6	5.2	3.6
Neutral	4	5.8	4.0
Neutral	2	5.8	4.4
Mixed	2	6.0	3.2
Mixed	4	6.5	4.7
Mixed	6	6.7	4.4
Compatible	6	6.8	5.2
Compatible	4	6.8	6.0
Incompatible	4	7.2	4.5
Incompatible	2	7.7	5.6

Table 10. Mean percentage of errors in ascending order for all conditions

There are no obvious patterns that pop out from the ordering of the means for the conditions. A 3 (number of flankers: 2, 4 or 6) X 4 (compatibility condition: compatible, neutral, incompatible, mixed) Repeated Measures ANOVA revealed no significant main effect of compatibility condition [$F(3, 33) = 2.08$; $ms_{error} = 4.03$; $p > 0.05$] or number of flankers [$F(2, 22) = 0.27$; $ms_{error} = 20.66$; $p > 0.05$]. However, a significant interaction between the compatibility condition and number of flankers was found [$F(6, 66) = 2.43$; $ms_{error} = 5.29$; $p < 0.05$].

A series of Tukeys were conducted to see where the significant differences lie and the results are presented in blocks according to the number of flanker conditions (see table 11- 13 below).

	Compatible	Neutral	Incompatible
Neutral	q = 2.13 p > 0.05	*	*
Incompatible	q = 5.38 p < 0.05	q = 3.25 p > 0.05	*
Mixed	q = 2.37 p > 0.05	q = 0.24 p > 0.05	q = 3.00 p > 0.05

Table 11. Differences between the compatibility conditions with 2 flankers

	Compatible	Neutral	Incompatible
Neutral	q = 1.72 p > 0.05	*	*
Incompatible	q = 0.73 p > 0.05	q = 2.46 p > 0.05	*
Mixed	q = 0.53 p > 0.05	q = 1.19 p > 0.05	q = 1.26 p > 0.05

Table 12. Differences between the compatibility conditions with 4 flankers

	Compatible	Neutral	Incompatible
Neutral	q = 2.82 p > 0.05	*	*
Incompatible	q = 2.70 p > 0.05	q = 0.11 p > 0.05	*
Mixed	q = 0.06 p > 0.05	q = 2.76 p > 0.05	q = 2.64 p > 0.05

Table 13. Differences between the compatibility conditions with 6 flankers

The Tukeys show that the compatible and incompatible condition significantly differed for the 2 flanker condition. This is in line with the compatibility effect but could not be generalised across the 4 and 6 flanker conditions' as no other differences were significant.

4.6.4 Discussion

The results from the RT data were quite unexpected. The compatibility effect was only partially observed here in that the incompatible flanker condition generated longer RTs than the compatible condition for all number of flankers, but these differences did not reach statistical significance. The results also showed that the neutral condition did not consistently generate intermediate RTs between the compatible and incompatible conditions, which, is inconsistent with the classical compatibility effect. Furthermore, there was no discernable pattern in the percentages of errors across conditions.

It is thought that the absence of the classic compatibility effect here might be due to the quality of stimuli used. Previous flanker task experiments did not use arbitrary shapes as stimuli. Rather, they used letters or arrows. It is thought that the strength of association between the stimulus shapes and their required response may not be strong enough for the flankers to affect responding to the target. The compatibility effect may be more likely to be observed with stimuli that have strong stimulus and response associations. Experiment 3 therefore used arrows as stimuli.

4.7 Experiment 3: Method

Rösler & Finger (1993) and Fournier, Scheffers, Coles, Adamson & Abad (1997) found a stronger compatibility effect when the targets were arrows as compared to slashes and letters (see section 1.7). Rösler & Finger also found that responses were faster when the targets were arrows. It is thought that arrows produce a stronger compatibility effect and faster responding because arrows have stronger S-R associations with a directional response. Thus, arrows were used as stimuli in this experiment in order to generate a strong compatibility effect.

4.7.1 Participants

Again, 12 undergraduates from Aston University took part in this experiment and received both 1-hour's worth of research credit or a chocolate bar and soft drink. However, due to a computer error, 2 participants data could not be included. Thus, only 10 of the participant's results were included in the analysis.

4.7.2 Apparatus and Stimuli

The stimuli were presented on a Macintosh IIsx and the trials were generated using the Superlab package version 1.4, developed by Cedrus Corporation.

4.7.3 Design

The design was identical to Experiment 2 with the exception that the stimuli were arrows, with a right pointing arrow mapped onto right hand response, and a left

pointing arrow mapped onto a left hand response and a circle served as a neutral flanker. Figure 4 below shows the stimulus for the compatibility conditions.

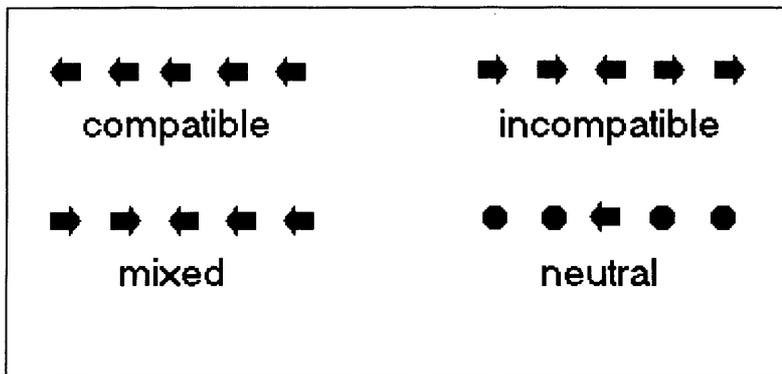


Figure 4. Examples of the compatibility conditions

The stimulus size is consistent with that for Experiments 1-2 and subtended a visual angle of 0.76 degrees. Participants were required to make a left hand key press to a left pointing arrow and a right pointing key press to a right pointing arrow. Again the keys 'C' and 'M' were used because of their equidistance from the centre of the keyboard. Because of the intrinsic association between the stimulus and response, the response mapping was not counterbalanced. The fixation circle in Experiment 2 was replaced with a fixation cross here because circles were used as neutral flankers in this experiment.

4.7.4 Procedure

The procedure was identical to Experiment 2. Participants were presented with the instructions on a computer screen were instructed to respond only to the middle

shape whilst ignoring the outer shapes. They were informed that a fixation cross indicates where the middle shape will appear and were instructed to stare at this cross as one second later the cross would be replaced by the shapes. They were asked to respond as quickly as possible whilst also being accurate.

4.8 Experiment 3: Results

4.8.1 Analysis of Reaction Times

Experiment 3 produced the quickest means to date (range 359 – 391ms) see Table 14 below) which are consistent with the findings of Rösler and Finger (1993) and Fournier, Scheffers, Coles, Adamson & Abad (1997) in that responses to arrows are relatively fast due to the intrinsic association with a directional response.

Compatibility Condition	No. of Flankers	Mean RT	SD
Compatible	2	359	36.5
Neutral	2	366	35.5
Compatible	6	370	38.7
Mixed	2	371	39.2
Incompatible	2	376	46.8
Neutral	6	377	38.8
Compatible	4	378	60.3
Neutral	4	380	62.5
Mixed	6	382	52.5
Incompatible	6	387	63.0
Incompatible	4	388	53.9
Mixed	4	391	69.6

Table 14. Mean RTs (ms) in ascending order for all conditions

There were 1.67% outliers in this data that were dealt with in the same way as Experiments 1 and 2.

Similarly to Experiment 2, a main effect of compatibility condition [$F(3,27) = 10.36$; $m_{\text{error}} = 126.8$; $p < 0.000$] but not number of flankers was found [$F(2, 18) = 2.42$; $m_{\text{error}} = 1156.40$; $p > 0.05$]. The ordering of the means for the combined compatibility conditions (across the number of flanker conditions) are consistent with the compatibility effect and are shown in Table 15 below.

Compatibility Condition	Mean RT	SD
Compatible	369	45.5
Neutral	374	45.9
Mixed	381	53.9
Incompatible	384	53.3

Table 15. Mean RTs (ms) in ascending order for the compatibility conditions

Furthermore, the mixed condition produced faster RTs than the incompatible condition, which offers support for the AASD model. However, the difference between these conditions is very small (3ms) and a series of Tukey tests (see Table 16 below) showed that the difference between the mixed and incompatible condition was not significant.

	Compatible	Neutral	Incompatible
Neutral	q = 2.47 p > 0.05	*	*
Incompatible	q = 7.06 p < 0.001	q = 4.60 p < 0.05	*
Mixed	q = 5.85 p < 0.05	q = 3.39 p > 0.05	q = 1.21 p > 0.05

Table 16. Differences between the compatibility conditions

The means for all the conditions are given in Table 14. For all of the compatibility conditions, the RTs increase as the number of flankers goes from 2, to 6 and then to 4. It is hard to determine the origin of this pattern given the complications in terms of how the size and quality of the visual attentional field might vary. However, no significant interaction between the compatibility conditions and number of flankers was found [$F(6, 54) = 0.32$; $ms_{error} = 158.05$; $p > 0.05$].

Again, the magnitude of the compatibility effect is small compared to previous studies (the difference between the compatible and incompatible conditions is 15ms here compared to around 40ms found in previous studies). Thus, again there may be a methodological flaw that dampens down the compatibility effect and might be responsible for the difference between the mixed and incompatible conditions not reaching significance.

4.8.2 Comparison of the Compatible Condition with 2, 4 and 6 Flankers

The ordering of the means for the compatible conditions (presented in Table 12 above) indicate that 2 flankers produced the fastest RTs followed by 6 flankers and then 4 flankers. This suggests that there is no facilitation due to additional compatible flankers within a stimulus array.

4.8.3 Analysis of Errors

The mean percentage of errors are presented in Table 17 below. There were 6.7% outliers in this data. The outliers were treated consistently with the previous experiments in that they were substituted for the highest value generated for that condition that was not an outlier.

Compatibility Condition	No. of Flankers	Mean %age	SD
Neutral	2	3.0	3.3
Compatible	4	3.2	3.4
Compatible	6	3.2	2.5
Neutral	4	3.4	2.9
Mixed	6	3.9	2.6
Compatible	2	4.1	4.6
Neutral	6	4.1	4.1
Mixed	4	4.8	3.4
Incompatible	6	4.8	4.4
Mixed	2	5.6	5.1
Incompatible	4	6.3	5.1
Incompatible	2	7.3	5.4

Table 17. Mean percentage of errors for all conditions in ascending order

There does not seem to be any discernable pattern in the percentage of errors in relation to the number of flanker conditions and a 3 (number of flankers) X 4 (compatibility condition) Repeated Measures ANOVA showed there to be no significant main effect of number of flankers [$F(2, 18) = 2.12$; $ms_{error} = 4.55$; $p > 0.05$].

The ANOVA did however, find a significant main effect of compatibility condition [$F(3, 27) = 8.15$; $ms_{error} = 5.73$; $p < 0.001$] and there was no significant interaction between the compatibility condition and the number of flankers [$F(6, 54) = 1.69$; $ms_{error} = 3.77$; $p > 0.05$]. The means presented in Table 17 show that for all number of flanker conditions, the incompatible condition produced the highest percentage of errors followed by the mixed condition and then the compatible condition with neutral flankers falling somewhere between the incompatible and compatible conditions (with the exception of the neutral condition with 2 flankers). This ordering of means is consistent with the compatibility effect (with the noted exception). The combined means for the compatibility conditions are shown in Table 18 below and mirror the pattern of the RT data.

Compatibility Condition	Mean %age	SD
Compatible	3.5	3.4
Neutral	3.5	3.5
Mixed	4.8	3.8
Incompatible	6.1	4.9

Table 18. Mean percentage of errors in ascending order for the compatibility conditions

A series of Tukey tests were performed and the results are presented in Tables 19 below.

	Compatible	Neutral	Incompatible
Neutral	q = 0.05 p > 0.05	*	*
Incompatible	q = 5.95 p < 0.01	q = 6.01 p < 0.01	*
Mixed	q = 2.89 p > 0.05	q = 2.94 p > 0.05	q = 3.06 p > 0.05

Table 19. Differences between the compatibility conditions

The only significant differences were between the incompatible and compatible conditions and between the incompatible and neutral conditions and these are consistent with the compatibility effect.

4.8.4 Discussion

The RT data show that the ordering of the means is in line with the compatibility effect and the prediction made by the AASD model that the mixed condition would produce faster RTs than the incompatible condition. The compatibility effect was significant here, but the difference between the mixed and incompatible conditions was not. However, this might be due to the magnitude of the compatibility effect that is again small here compared to previous studies. The error data also showed that the ordering of the means for the combined compatibility conditions are consistent

with the compatibility effect with the exception that the neutral condition for 2 flankers generated faster RTs than the compatible condition with 2 flankers.

After re-examination of the experimental set-up, it was noticed that the size of the stimuli is rather large compared to the majority of previous flanker task studies. The stimulus size used in these studies is 0.76 of the visual angle which is the same stimulus size used by Lavie (1997). The present study used the same size as Lavie's stimuli because the stimulus used in the first 3 experiments were of the same nature adopted in her experiments - namely shapes. However, Lavie's study required that the participants responded to 2 stimulus dimensions (colour and shape) whereas only the shape dimension was used here. Also, Lavie's study was a combination of a flanker task and a go – no go task. Experiment 4 therefore aimed to increase the magnitude of the compatibility effect by using smaller stimulus in the hope that the range of means would be larger and the compatibility effect would be fully observed.

4.9 Experiment 4: Method

Experiment 3 is an improvement on Experiments 2 and 1 because the ordering of the mean RTs for the compatibility conditions were consistent with the compatibility effect and the prediction made that the mixed condition would generate faster RTs than the incompatible condition was partially upheld. However, the difference between the mixed and incompatible difference did not reach statistical significance and again the magnitude of the compatibility effect was small. The improvement in Experiment 3 is thought to be because the S-R associations were stronger than those in Experiments 1 and 2. It is clear though, that there is still some methodological flaw that is dampening down the compatibility effect. After comparing the methodology used here to previous experiments it was noticed that the size of the stimulus used was comparatively large. Furthermore, previous research (reported in section 1.8) has shown that the size of stimuli mediates the magnitude of the compatibility effect produced. This experiment therefore used a smaller stimulus size in the hope that the magnitude of the compatibility effect would be increased.

4.9.1 Participants

12 undergraduate students from Leicester University took part in this experiment and received 1-hour worth of credit for research hours (6 hours are required as part of the Psychology degree).

4.9.2 Apparatus and Stimuli

The trials were generated using SuperLab - Cedrus version 1.4 which was installed on a Pentium III PC. The stimuli were the same as the previous experiment but reduced in size.

4.9.3 Design

The design of this experiment was identical to Experiment 3 with the exception that the stimuli were smaller (0.36 of visual angle compared to 0.76 used previously).

4.9.4 Procedure

The procedure was also identical to Experiment 3.

4.10 Experiment 4: Results

4.10.1 Analysis of Reaction Times

There 0.83% of outliers in this data that were replaced with the highest value for that condition that was not an outlier. The ordering of the mean RTs are given in Table 20 below. The RTs here are a lot slower than in Experiment 3 (the ranges are 359-391ms in Experiment 3 and 425-489ms here) and the range of the means (64ms) is noticeably larger than those generated in Experiments 1-3 (32, 24 and 21 for experiments 3, 2 and 1 respectively). Thus, decreasing the size of the stimuli seems to increase the range of responding as well as the RTs in responding.

Compatibility Condition	No. of flankers	Mean RT	SD
Compatible	4	425	76.6
Neutral	4	427	75.5
Neutral	6	431	52.5
Compatible	6	433	55.7
Compatible	2	437	45.4
Mixed	4	439	85.2
Neutral	2	443	44.3
Mixed	6	451	50.0
Mixed	2	462	42.5
Incompatible	4	472	105.2
Incompatible	6	477	71.7
Incompatible	2	489	43.3

Table 20. Mean RTs (ms) in ascending order for all conditions

There does not seem to be any obvious pattern in the ordering of the means in relation to the number of flankers and a 3 (number of flankers: 2, 4 or 6) X 4 (compatibility condition: compatible, neutral, incompatible, mixed) Repeated Measures ANOVA revealed that there was no significant main effect of the number of flankers [$F(2, 22) = 0.53$; $merror = 6291.68$; $p > 0.05$]. However, similarly to Experiment 3, there does seem to be a strong pattern for the ordering of the number of flankers when each compatibility condition is looked at in isolation. The RTs for each compatibility condition seem to increase as the number of flankers goes from 4 to 6 to 2 flankers and the ranges for the number of flanker conditions are quite similar (52ms for 2 flankers; 47ms for 4 flankers and 46 for 6 flankers). The pattern

of means for Experiment 3 was not the same as here however. For Experiment 3, the RTs increase for each compatibility condition as the flankers went for 2 to 6 to 4 flankers. Why these patterns may have emerged is not clear. Similarly to Experiment 3, the ANOVA revealed that there is no significant interaction between the number of flankers and the compatibility condition [$F(6, 66) = 0.78$; $ms_{error} = 123.17$; $p > 0.05$].

A significant main effect of compatibility condition was found [$F(3, 33) = 40.74$; $ms_{error} = 435.11$; $p < 0.001$]. The combined means for the compatibility condition (shown in Table 21) show that the ordering of the means are consistent with compatibility effect and the prediction made that the mixed condition would produce faster RTs than the incompatible condition. Also, the difference between the incompatible condition and the compatible condition is quite large (49ms) and is a magnitude that is comparable to previous observations of the compatibility effect.

Compatibility Condition	Mean RT	SD
Compatible	431	59.1
Neutral	434	57.6
Mixed	450	61.0
Incompatible	480	75.7

Table 21. Mean RTs (ms) in ascending order for the compatibility conditions

A series of Tukey tests were performed to ascertain where the significant differences lie and the results are given in Table 22 below. All the differences are significant with the exception of the difference between the compatible and neutral conditions. Thus, the classic compatibility effect is observed in Experiment 4. The difference between the mixed and incompatible condition is also significant and as predicted by the AASD model.

	Compatible	Neutral	Incompatible
Neutral	q = 0.64 p > 0.05	*	*
Incompatible	q = 13.83 p < 0.001	q = 13.20 p < 0.001	*
Mixed	q = 5.44 p < 0.01	q = 4.80 p > 0.01	q = 8.40 p < 0.01

Table 22. Differences between the compatibility conditions

4.10.2 Comparison of the Compatible Condition with 2, 4 and 6 Flankers

The ordering of the mean RTs for the compatible conditions show that there is no additional facilitation due to additional compatible flankers as the RTs were quicker when there were 4 flankers followed by 6 flankers and then 2 flankers. However, given that for both Experiments 3 and 4 there was consistency across the compatibility conditions in terms of how the RTs increase in relation to the number of flankers, it is not possible to draw any strict conclusions as to whether compatible flankers facilitate responding in the absence of noise flankers. There may be some spurious effect that might be responsible for these patterns that might be related to

differences in perceptual load or processing resources of the task for instance. That these patterns differed between Experiments 3 and 4 suggests that there is some task relevance that would be responsible for the consistencies. However, because there were no significant differences between the number of flanker conditions and no significant interaction between the number of flankers and the compatibility conditions in either experiment, no strict conclusions can be drawn.

4.10.3 Analysis of Errors

The mean percentage of errors contained 7.6% outliers and the outliers were again substituted for the highest value for that condition that was not an outlier. The mean percentage of errors for each condition can be seen in Table 23 below.

Compatibility Condition	No. Flankers	Mean %age	SD
Compatible	4	2.2	3.1
Neutral	2	2.5	2.1
Compatible	2	2.8	3.7
Compatible	6	3.1	4.5
Mixed	2	3.4	2.9
Neutral	4	5.3	8.0
Neutral	6	5.5	8.3
Mixed	6	5.7	6.4
Mixed	4	7.1	8.9
Incompatible	2	10.1	9.2
Incompatible	6	15.3	14.9
Incompatible	4	16.1	17.0

Table 23. Mean percentage of errors in ascending order for all conditions

The means show that overwhelmingly, the incompatible condition generated more errors than all the other compatibility conditions. Indeed, a 3 (number of flankers) X 4 (compatibility condition) Repeated Measures ANOVA revealed a significant main effect of compatibility condition [$F(3, 33) = 13.4$; $ms_{error} = 65.9$; $p < 0.001$] but no significant main effect of number of flankers [$F(2, 22) = 3.2$; $ms_{error} = 40.6$; $p > 0.05$] was found. The combined means for the compatibility condition (given in Table 24 below) again mirror the RT data and show that overwhelmingly there are more errors generated in the incompatible condition compared to the other conditions.

Compatibility Condition	Mean %age	SD
Compatible	2.7	3.7
Neutral	4.4	6.7
Mixed	5.4	6.5
Incompatible	13.8	13.9

Table 24. Mean percentage of errors in ascending order for the compatibility conditions

A series of Tukey analyses (see Table 25 below) show that the mean percentage of errors for the incompatible condition differed significantly with all the other conditions and that no other differences were significant. Thus, the incompatible condition generates more errors than either the compatible, neutral, or mixed conditions.

	Compatible	Neutral	Incompatible
Neutral	q = 1.27 p > 0.05	*	*
Incompatible	q = 8.20 p < 0.05	q = 6.93 p < 0.05	*
Mixed	q = 1.97 p > 0.05	q = 0.69 p > 0.05	q = 6.24 p < 0.05

Table 25. Differences between the compatibility conditions

However, an interaction between the number of flankers and the compatibility condition was also found. [$F(6, 66) = 3.7$; $m_{\text{error}} = 25.8$; $p < 0.05$]. A series of Tukeys show that these differences were manifest in 4 and 6 flanker conditions only. There were no significant differences between the compatibility conditions for 2 flankers. Thus, it seems that the activation generated by 2 incompatible flankers is not salient enough to disrupt accuracy.

	Compatible	Neutral	Incompatible
Neutral	q = 0.15 p > 0.05	*	*
Incompatible	q = 3.09 p > 0.05	q = 3.24 p > 0.05	*
Mixed	q = 0.22 p > 0.05	q = 0.38 p > 0.05	q = 2.87 p > 0.05

Table 26. Differences between the compatibility conditions with 2 flankers

	Compatible	Neutral	Incompatible
Neutral	q = 1.34 p > 0.05	*	*
Incompatible	q = 5.94 p < 0.05	q = 4.60 p < 0.05	*
Mixed	q = 2.10 p > 0.05	q = 0.76 p > 0.05	q = 3.84 p < 0.05

Table 27. Differences between the compatibility conditions with 4 flankers

	Compatible	Neutral	Incompatible
Neutral	q = 1.02 p > 0.05	*	*
Incompatible	q = 5.18 p < 0.05	q = 4.16 p < 0.05	*
Mixed	q = 1.08 p > 0.05	q = 0.07 p > 0.05	q = 4.10 p < 0.05

Table 28. Differences between the compatibility conditions with 6 flankers

4.10.4 Discussion of Results from Experiments 1 - 4

After a few teething problems associated with methodology, Experiment 4 finally produced the compatibility effect of a magnitude comparable to those reported in previous studies. Experiments 1 - 4 indicate, in line with previous research, that the quality of the stimuli in terms of the associative strength between the stimulus and the response plays an important role in mediating the compatibility effect. The compatibility effect is larger when the stimuli have a more intrinsic association with the response (arrows) compared to when the stimulus response mapping is arbitrary (such as shapes). This is consistent with studies reported in section 1.7 earlier such as

those by Rösler & Finger (1993) and Fournier, Scheffers, Coles, Adamson & Abad (1997) who also found that the compatibility effect is larger when the S-R association is strong such as when an arrow is mapped onto a directional response.

Furthermore, increasing the number of trials resulted in a decrease in the response times (as seen by comparing Experiment 1 and Experiment 2) and increased the range of the means for the RT data. It is thought that this is because the S-R association is strengthened with practice.

It was also found that smaller stimuli seem to produce a larger compatibility effect compared to larger stimuli (comparison of Experiment 3 and Experiment 4). This is consistent with the findings of Eriksen & Schultz (1979) and Ridderinkof, van der Molen & Bashore (1995) reported in section 1.8. It is not clear why this might be the case, but some may argue, based on previous theory and research, that it is due to the smaller flankers being more within the visual attentional field compared to larger flankers (see section 1.14 for a review). The distance between flankers and the target was always equal to the width of the stimuli, so the flankers with smaller stimulus size would span a smaller range of distance than when the stimuli were larger.

However, it is clear that even the flankers with the larger stimulus size are still processed to the extent that they affect responding because a partial compatibility

effect was observed in Experiment 3. This appears to support to the gradient metaphor of attention in that it suggest that the flankers at further eccentricities are processed but their effect on responding is degraded compared to flankers at closer proximities to the target. However, if this was the case we would expect 6 incompatible flanker conditions to still generate longer RTs than 4 or 2 incompatible flanker conditions (providing that the outer flankers still fell within the visual attentional field) but this was not the case in either Experiments 3 or 4. Indeed Experiments 3 and 4 produced novel results in terms of the pattern of RTs across the compatibility conditions for the number of flankers in that the RTs increased for all compatibility conditions as the number of flankers went from 2 to 6 and then 4 flankers for Experiment 3 and as the flankers went from 4 to 6 and then to 2 flankers for Experiment 4. Furthermore, for both Experiments 3 and 4 there was no significant main effect of number of flankers or interaction between the number of flankers and the compatibility condition so we can assume that these patterns are chance results. It might be fair then to suggest that the size of a stimulus moderates the strength of activation that it generates.

Support for the AASD model was obtained by the significant differences between the mixed and incompatible conditions. Experiment 4 and some evidence in Experiment 3 showed that stimulus arrays that contain a mixture of compatible and incompatible flankers generated faster RTs than arrays that contain purely incompatible flankers. The AASD model predicted this on the grounds that the activation received by the

incorrect response channel (from incompatible flankers) is counteracted by activation received in the correct response channel (from compatible flankers). It is thought that the compatible flankers facilitate responding and incompatible (and neutral?) flankers slow responding. It is also thought that the activation from each flanker has an additive effect on RT in that the activation that they generate accumulates within the corresponding response channels. That is, the activation generated by each individual flanker generates the same strength of activation (providing they are of the same nature i.e. the same stimulus dimension and have the same S-R associative strength) and this activation is pooled in the corresponding response channels.

That compatible and incompatible flankers seem to cancel each other out suggests that compatible flankers have a facilitative affect on RT. This was previously found in letter detection tasks but not in the flanker task (see section 1.5 for a review). The AASD model accounted for these inconsistencies by suggesting that no facilitation is observed in compatible flanker conditions because performance should already be at ceiling level. That is, under conditions where no alternative response channel (to the correct response channel) is activated, then, sufficient certainty that the most activated response is indeed the correct response is immediate.

Comparisons between the compatibility conditions with 2, 4 and 6 flankers found no consistent pattern in terms of the ordering of the means and there was no evidence that additional compatible flankers facilitate responding. Thus, the prediction made

by the AASD model in that there will be no facilitation from compatible flankers when there is no response competition is partially upheld. However, the problems of looking at the compatibility conditions across the number of flankers conditions makes it hard to draw strict conclusions.

The AASD model can also account for the pattern of errors here and in previous research. The AASD model suggests that the pattern of errors should mirror that of RT because there is a greater probability of making an incorrect response when the difference between competing response channels is small. Experiment 4 provides strong evidence that the pattern of errors mirrors that of RT although the differences between the mean percentages of errors were not all significant.

The experiments so far seem to have shown that compatible flankers facilitate responding (when there is response competition) and incompatible flankers slow responding and the effects of compatible and incompatible flankers cancel each other out. However, the mixed condition in the previous experiments used an equal number of compatible and incompatible flankers. It remains to be seen whether the proportion of compatible to incompatible flankers within a stimulus array mediate the extent of response slowing. The AASD model predicts the ratio of compatible to incompatible flankers within a stimulus array will mediate the extent of response slowing and percentages of errors in responding. It is thought that once all possible pairings of compatible and incompatible flankers have been calculated, the residual

flankers will determine the ordering of the mean RTs and percentages of errors for each condition.

Suggesting that the ratio of compatible to incompatible flankers will mediate the extent of response slowing is not the same as predicting that number of compatible flankers or the number of incompatible flankers per se, will show proportionate slowing. Indeed, no predictions were made in terms of interactions between the number of flankers and the compatibility conditions because of the arbitrary activation strength assigned to the target in making the predictions and also because as yet, we do not know whether the activation strength of the target is static across all conditions or whether it is variable. If the activation strength of the target is static, then, there might be a crossover effect where the activation generated by the flankers would outweigh that generated by the target. In such a case, the AASD model would predict that the number of errors generated by an incompatible stimulus array would increase to the point where the number of incorrect responses made would outweigh the number of correct responses made. This is because the activation strength in the incorrect response channel would be higher than that in the correct response channel. An interaction between the incompatible condition and the number of flankers would be expected at some number of flankers where this crossover effect would be observed.

On the other hand, the activation strength afforded the target might vary according to the task demands (like the zoom lens metaphor of attention). In stimulus arrays where the likelihood of an incorrect response is high for instance, the attention might be more focused on the target. This explanation is similar to Lavie & Cox's (1997) perceptual load theory that irrelevant information can be ignored given that the perceptual load of the task is sufficiently high. If one assumes that the perceptual load of the task is governed by how hard it is to make the correct response, then, the perceptual load of the task according to the AASD model is high if there is a high ratio of activation given to the incorrect response channel compared to the correct response channel (as in incompatible conditions). This idea has parallels with SDT in terms of response criterion setting for situational and task parameters.

It is very hard to extract evidence in favour of either a variable or static activation strength afforded the target from the experiments presented so far. The reason for this is because Experiment 1 showed that the number of flankers per se affects RTs. That is, the more flankers there are, the slower the RTs are. No compatibility effect was found in Experiment 1 though, which suggests that the perceptual load of the task (to use Lavie's 1995 theory) might have been sufficiently high in order for the flankers properties not to affect responding (i.e. because no compatibility effect was observed). It is thought that the perceptual load of the task might have been too high because the participants had not developed a strong stimulus and response association due to the small number of trials that they performed. However, because

the RTs were affected by the number of flankers and not by the properties of the flankers (their compatibility), it seems that there may be resource limitations that are taken up by processing additional flankers.

Because of the problems associated with looking at the effects across the number of flanker conditions, the next experiment to be reported used only a 4 flanker array in order to ascertain whether the ratio of compatible to incompatible flankers mediates RT and the percentages of errors in responding. If the ratio of compatible to incompatible flankers does affect responding, this would provide more support for the idea that a response is based on the difference in accumulated activation strengths between competing response channels.

Chapter 5

The Ratio of Compatible to Incompatible Flankers

The AASD model predicts that each flanker within a stimulus array gives activation to the corresponding response channel and that this activation is accumulated and contributes to the difference in activation strength between competing response channels. It is thought that this difference in activation strength between competing response channels is the mechanism that response execution is based on. Thus, there should be an additive effect of each flanker on responding (except in compatible flankers arrays as discussed previous). Experiment 4 provided support for the idea that compatible and incompatible instances within a stimulus array serve to cancel each other out by showing that the mixed compatible and incompatible flanker condition produced faster RTs than purely incompatible flanker conditions. The mixed condition in Experiment 4 presented an equal number of compatible and incompatible flankers. Experiment 5 presented stimulus arrays that had unequal numbers of compatible and incompatible flankers in a five stimulus array (4 flankers and 1 target) to see whether the ratio of compatible to incompatible flankers produced a graded effect on RT and percentages of errors in responding.

Using ratios of compatible to incompatible flankers was a necessity because it is the only design that uses an equal number of flankers between trials without using neutral flankers. The number of flankers had to remain constant because of the

problems noted above in terms examining compatibility conditions across number of flanker conditions. Neutral flankers could not be used because they slow responding (although as yet we are not sure exactly how). Also, Experiments 1 - 4 have shown that the ordering of neutral conditions in relation to compatible and incompatible flankers has not been very consistent.

The AASD model predicts that a higher ratio of incompatible flankers to compatible flankers would result in longer RTs and a higher percentage of errors compared to smaller ratios of incompatible to compatible flankers. This is because when there are more incompatible flankers than compatible flankers, the residual activation after the compatible and incompatible flankers have cancelled each other out would serve to reduce the accumulated activation strength difference. That is, the more residual incompatible flankers there are (the more the residual activation in the incorrect response channel) the smaller the accumulated activation strength difference between the response channels. Conversely, compatible flankers would increase the accumulated activation strength difference in favour of the correct response channel. Thus, higher ratios of compatible to incompatible flankers would generate faster RTs and fewer errors than smaller ratios of compatible to incompatible flankers.

5.1 Experiment 5: Method

5.1.1 Participants

12 undergraduate students at Leicester University took part in this experiment voluntarily.

5.1.2 Apparatus and Stimuli

The trials were generated using SuperLab - Cedrus version 1.4 which was installed on a Pentium III PC.

5.1.3 Design

The stimuli were left and right pointing arrows of the same size and shape as in Experiment 4. No other shapes were used. There were always 4 flankers (2 on either side of the target) that were either compatible or incompatible with the target. A linear array was again used, as there was no significant main effect of number of flankers or a significant interaction between the number of flankers and the compatibility conditions in Experiment 4. There were 5 conditions that vary according to the number of incompatible flankers within the array: 0, 1, 2, 3, or 4 incompatible flankers. The list below equates each condition to the ratio of incompatible to compatible flankers there is in each condition and also gives the corresponding percentage of incompatible flankers to compatible flankers.

Condition	Ratio	Percentage
0	0:4	0%
1	1:4	25%
2	2:4	50%
3	3:4	75%
4	4:4	100%

The RTs and percentages of errors are expected to increase as the ratio and percentage of incompatible to compatible flankers increase. Although it is the ratio of incompatible to compatible flankers rather than the number of incompatible and compatible flankers per se that is important, the conditions will be referred to as the number of incompatible flankers that they contain for simplicity. Furthermore, because the number of flankers is always four, it is expected that the number of incompatible flankers there are within the array will predict the ordering of the conditions in terms of RTs and percentage of errors made.

The number of possible permutations of the locations of the incompatible flankers in an array differs depending on the number of incompatible flankers within that array. The possible permutations for the locations of the incompatible flankers are shown in Figure 5 below. Because there is an unequal number of permutations for each condition, care had to be taken to present an equal number of trials for each condition. This meant that some permutations had to be repeated. Two experiments

were designed so that the trials that were repetitions could be counterbalanced across the experiments.

Another potential problem with the design of this experiment arises due to the target always being presented with the centre of a linear array. There is a well known phenomenon called the 'pop-out' (see Treisman & Souther for an example) effect whereby, stimuli that are easily discriminable from other stimuli within a stimulus array, often captures attention. Responding to a stimulus that is easily discriminable from other stimuli is usually faster than responding to a target that is less discriminable within a stimulus array. The discriminability of a target can be manipulated in terms of the target having a distinguishable feature, (i.e. a colour) that differs from all of the other stimuli. A target has shown to 'pop-out' from a stimulus array if it is embedded in an array that contains identical stimuli (see Theeuwes & Lucassen 1994 for an example).

The 'pop-out' effect presents a potential problem when examining the configuration of the stimuli for the conditions in this experiment. The target is more discriminability in the 4 (4:0) incompatible flanker condition compared to all the other conditions as the target is embedded in a stimulus array where all the other stimuli are identical. Thus, a pop-out effect may be expected that would result in faster responding to the target for the 4 (4:0) flanker condition. For this reason, we might expect that the compatibility effect would be dampened down. However, it is very difficult to

control for possible configural effects with a design that aims specifically to examine the ratio of flanker types.

NUMBER OF INCOMPATIBLE FLANKERS (RATIO)	NUMBER OF PERMUTATIONS	POSSIBLE PERMUTATIONS
0 (0:4)	2	<<<<< >>>>>
1 (1:3)	8	>>>>< >>><> ><>>> <>>>> <<<<< <<<<< <><<< ><<<<
2 (2:2)	12	>>><< ><>< ><><> <>><< <>><> <<>>> >><<< ><<< ><<<> <><<< <><<> <<<<>
3 (3:1)	8	>><>< >><<> ><>>> <>>>> <<>>> <<><< <>><< ><><<
4 (4:0)	2	>><>> <<><<

Figure 5. Possible permutations for the incompatible flanker locations

There were 2 practice blocks of 30 trials (6 trials of each condition) followed by 4 experimental blocks of 120 trials (24 trials of each condition).

5.1.4 Procedure

Participants were again instructed to respond to the target whilst ignoring the flankers and to respond as quickly as possible whilst also being accurate. They were required to make a left hand response (the 'C' key on the keyboard) to a left pointing arrow and a right hand response (the 'M' key on the keyboard) to a right pointing arrow. Again all the other aspects of this experiment are the same as the previous

experiment with the noted exceptions. As with the previous experiment, a small, unfilled cross, served as a fixation point that was replaced 1000ms later by the target and flankers and a cut-off time of 3000ms was enforced whereby the next trial automatically commenced should the participant fail to respond within that time.

5.2 Experiment 5: Results

5.2.1 Analysis of Reaction Times

There were no outliers in this data. The ordering of the mean RTs are as expected (and can be seen in Table 29 below) with the exception for the conditions that had 1 or 0 incompatible flankers. The range of the means is very similar to that of Experiment 4 (59ms here compared to 64ms in experiment 4). The Standard Deviations here however, differed markedly to those obtained in Experiment 4. The range of SDs here is a lot smaller in size and range (21.3-26.3) compared to those of Experiment 4 (42.5-105.2). It is thought that this might be because there were more conditions in Experiment 4 (12 conditions) that differed on two levels whereas here there were only 5 conditions that differed on one level only. Thus, we would expect higher variability in performance for Experiment 4 compared to here.

No. of Incompatible Flankers (ratio)	Mean RT	SD
1 (1:4)	425	22.5
0 (0:4)	426	26.2
2 (2:2)	440	26.3
3 (3:1)	459	21.3
4 (4:0)	484	24.3

Table 29. Mean RTs (ms) in ascending order for all conditions

A One Way Repeated Measures ANOVA (5 levels of number of incompatible flankers 0-4) revealed that there is a significant difference between the means [$F(4, 44) = 62.73$; $ms_{error} = 118.86$; $P < 0.000$]. A series of Tukey tests were performed (and can be seen in Table 30 below) which showed that all the differences were significant except for that between 0 (0:4) and 1 (1:3) incompatible flanker conditions. It may be that the activation generated by the 1 incompatible flanker did not generate enough activation to significantly reduce the accumulated activation strength difference in order to require further processing to reach sufficient certainty that the most activated response is the correct response.

	0 (0:4)	1 (1:3)	2 (2:2)	3 (3:1)
1 (1:3)	q = 0.39 p > 0.05	*	*	*
2 (2:2)	q = 4.45 p < 0.05	q = 4.84 p < 0.05	*	*
3 (3:1)	q = 10.35 p < 0.001	q = 10.74 p < 0.001	q = 5.90 p < 0.01	*
4 (4:0)	q = 18.42 p < 0.001	q = 18.82 p < 0.001	q = 13.98 p < 0.001	q = 8.08 p < 0.001

Table 30. Differences between each condition

These results support the AASD model in the prediction that the ratio of compatible to incompatible flankers generates a graded effect on RTs with a higher ratio of incompatible to compatible flankers generating longer RTs compared to when the ratio is smaller.

That the 4 (4:0) incompatible flanker condition differed significantly from all the conditions suggests that either, the ‘pop-out’ effect was not observed here, or that the ‘pop-out’ effect was not sufficiently potent to disrupt the slowing of RTs associated with incompatible stimuli to the extent that the compatibility effect was not observed. It may be for example, that the differences between the 4 (4:0) and 0 (0:4) incompatible flanker condition would have been even greater if the problem of the discriminability of the target in relation to the flankers was controlled for.

5.2.2 Analysis of Errors

The ordering of the mean percentage of errors for the conditions is exactly as predicted, but, like the RT data, the difference between the 0 (0:4) and 1 (1:3) incompatible flanker conditions is small (see Table 31 below). There were 1.67% outliers in this data that were replaced with the highest value that was not an outlier for that condition.

No. of Incompatible Flankers (ratio)	Mean %age	SD
0 (0:4)	1.1	1.0
1 (1:3)	1.7	1.9
2 (2:2)	2.5	2.6
3 (3:1)	4.4	3.3
4 (4:1)	6.1	3.1

Table 31. Mean percentage of errors in ascending order for all conditions

A One Way (number of incompatible instances with 5 levels 0-4) Repeated Measures ANOVA, revealed that there is a significant difference between the means [$F(4, 44) = 15.46$; $m_{error} = 3.25$; $P < 0.000$]. A series of Tukey tests were performed (and

can be seen in Table 32 below). The results show that the 4 (4:0) incompatible flanker condition produced significantly higher percentages of errors than 2 (2:2), 1 (1:3), or 0 (0:4) incompatible flanker conditions. Also, conditions that contain 3 (3:1) incompatible flankers generated significantly higher percentages of errors than when there were only 1 (1:3) or 0 (0:4) incompatible flankers. No other differences were significant.

	0 (0:4)	1 (1:3)	2 (2:2)	3 (3:1)
1 (1:3)	q = 1.18 p > 0.05	*	*	*
2 (2:2)	q = 2.69 p > 0.05	q = 1.51 p > 0.05	*	*
3 (3:1)	q = 6.34 p < 0.001	q = 5.16 p < 0.01	q = 3.65 p > 0.05	*
4 (4:0)	q = 9.54 p < 0.001	q = 8.36 p < 0.001	q = 6.85 p < 0.001	q = 3.20 p > 0.05

Table 32. Differences between the mean percentages of errors for each condition

5.2.3 Discussion

The results here offer strong support for the prediction that higher ratios of incompatible to compatible flankers increase RTs and the percentage of errors in responding. The ordering of the means was exactly as predicted with the exception 1 (1:3) and 0 (0:4) incompatible flanker conditions in the RT data. All of the differences in the RT data were significant except between 1 (1:3) and 0 (0:4) conditions. It could be that the level of activation received by the incorrect response

channel when there was just 1 incompatible flanker was not sufficient to reduce the difference between the activation strength to significantly affect RTs in responding. Furthermore, the pattern of errors in responding seems to mirror that of the RT data although not all the differences between the conditions were significant.

That the ratio of incompatible to compatible flankers mediates RT suggests, in line with the AASD model, that it is the difference in activation strength between competing response channels on which a response is based rather than a threshold level of activation being achieved. If a response is executed on the basis of a threshold level of activation being reached, then the ratio of compatible to incompatible flankers should not show a graded effect on responding. One might argue that the Race models (mentioned in section 2.1) might be able to explain the graded effect on RT and error patterns according to the ratio of compatible to incompatible flankers in terms of statistical facilitation (quicker RTs due to more correct response channels taking part in the race). However, the Race model cannot also account for how the pattern of errors mirrors that of RT data if presumably the channels that 'lose the race' do not contribute to response preparation. Thus, the AASD model offers a more comprehensive explanation for these findings than do Race models.

Race models would also suggest that RTs for 6 compatible flanker arrays would produce quicker RTs than compatible arrays with 4 or 2 flankers. There is no

evidence of facilitation due to additional compatible flankers found in these experiments. Furthermore, Race models do not offer much scope to explain how information from different stimulus dimensions can interact in terms of how they affect responding. The next chapter examines whether the ratio of compatible to incompatible flanker properties from different stimulus dimensions also produces the same graded effect as found here.

Chapter 6

Two Stimulus Dimensions

Experiment 5 showed that the ratio of compatible to incompatible flankers within a stimulus array mediates the extent to which response slowing is observed in the flanker task. It is thought that the activations generated by each flanker are pooled in the corresponding response channel and this pooling of activation mediates the extent of response slowing. It would be interesting to see whether the activation generated from different stimulus dimensions is also pooled and whether the ratio of compatible to incompatible properties across stimulus dimensions (e.g. colour and shape) also mediates the extent of response slowing. Although the AASD model does not attempt to explain how stimulus evaluation processing is carried out, it is assumed to be in line with previous research (such as Smid, Mulder, Mulder & Brands 1992, and Smid and Heinze 1997, mentioned in section 1.13), in that colour and shape information are processed separately.

Experiment 6 was designed to test whether the activations generated from the stimulus dimensions of colour and shape are pooled by varying the number of compatible and incompatible properties within a stimulus array according to colour/shape or both. It is thought that if the colour and shape information is pooled, then there should be an additive effect of the activations generated from these dimensions that will be reflected in the extent of RT slowing and percentages of errors. Shapes are used here as opposed to arrows (which have a greater tendency to

generate the compatibility effect) because it is thought that arrows have a stronger S-R association to a direction response compared to colour and this might result in stronger activations generated by the arrow dimension compared to the colour dimension. This would dampen any possible additive effects of colour and shape. Thus, arbitrary shapes are used because they do not have an intrinsic association with a directional response.

6.1 Experiment 6: Method

6.1.1 Participants

12 undergraduates at Leicester University participated in this experiment voluntarily.

6.1.2 Apparatus & Stimuli

SuperLab - Cedrus version 1.4 installed on a Pentium III PC was again used to generate the trials. The stimuli were created using Paint.

6.1.3 Design

Experiment 6 uses only 2 flankers because having two stimulus dimensions increases the complexity of possible permutations compared to when there is only one stimulus dimension. As in Experiment 5, the flanker attributes were either compatible or incompatible hence there were no neutral colours or shapes presented within a stimulus array. A target was either a red filled circle or a green filled square that

again subtended $0.36^\circ \times 0.36^\circ$ of visual angle. Because the flankers presented only compatible or incompatible properties, the flankers were either red or green, and were either a square or a circle. However, in this experiment, the flankers could have either an incompatible colour, an incompatible shape or both an incompatible colour and shape. Examples of these conditions are illustrated in Figure 6 below.

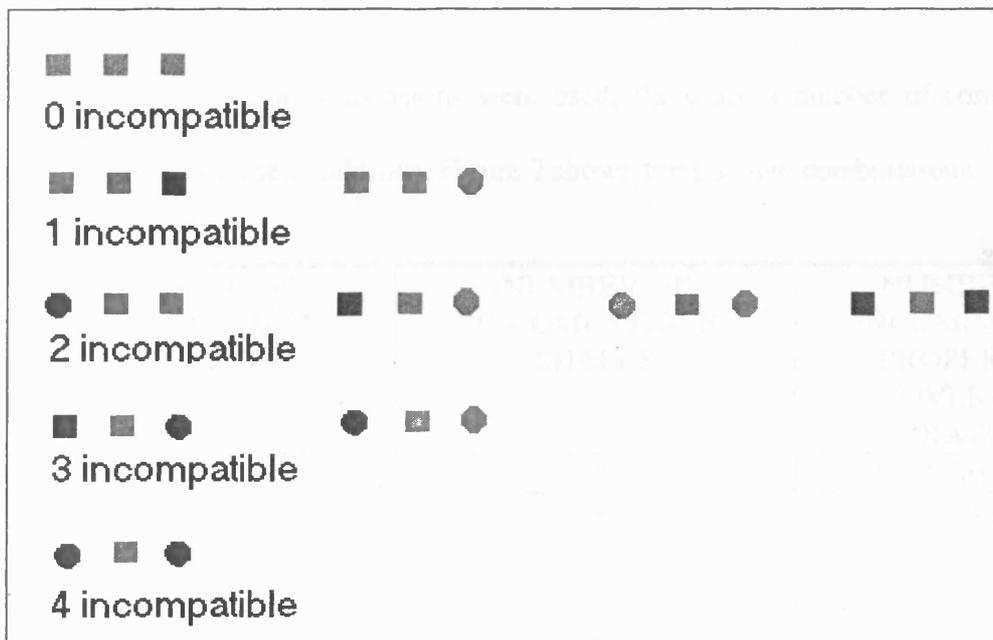


Figure 6 Examples of the conditions for a green (shown as light grey here) square target

There were 5 conditions that for simplicity, are defined by the number of incompatible properties (either colour or shape) there are in a stimulus array: 0 – 4 incompatible properties. The list below equates the ratio of incompatible to compatible properties that there were in a stimulus array to the conditions.

Condition	Ratio	Percentage
0	0:4	0%
1	1:4	25%
2	2:4	50%
3	3:4	75%
4	4:4	100%

Because two stimulus dimensions were used, there are a number of combinations that can make up the conditions. Figure 7 shows the possible combinations.

NUMBER OF INCOMPATIBLE COLOURS	NUMBER OF INCOMPATIBLE SHAPES	NUMBER OF INCOMPATIBLE PROPERTIES OVERALL (RATIO)
0	0	0 (0:4)
1	0	1 (1:3)
0	1	1 (1:3)
2	0	2 (2:2)
0	2	2 (2:2)
1	1	2 (2:2)
1	1	2 (2:2)
1	2	3 (3:1)
2	1	3 (3:1)
2	2	4 (4:0)

Figure 7. The possible combinations of incompatible shape and colour within the flankers

There are different numbers of combinations of shape and colour that can make up each condition. For 0 (0:4) and 4 (4:0) incompatible properties there is only 1 combination, for 1 (1:3) and 3 (3:1) incompatible properties there are 2 possible

combinations and for 2 (2:2) incompatible properties there are 4 possible combinations. This meant that some combinations had to be repeated to make up equal numbers of trials for each condition. There were also equal numbers of each condition in each of the practice and experimental blocks. There were 2 practice blocks of 30 trials (6 trials of each condition) followed by 4 experimental blocks of 120 trials (24 trials of each condition).

6.1.4 Procedure

The procedure is identical to Experiment 5 except participants were required to make one response to a green filled square and another response to a red filled circle. The S-R mapping was counterbalanced so that half of the participants made a left response to the red circle and a right response to the green square (the 'C' and 'M' keys respectively) and the other half of the participants were assigned the opposite S-R mapping. Also, a small cross served as a fixation point and like the previous experiments the cross was replaced 1000ms later by the target and flankers and a cut-off time of 3000ms was enforced whereby the next trial automatically commenced should the participant fail to respond. All the other aspects of the experiment were identical to Experiment 5 with the exception that there were 2 flankers instead of 4 flankers.

6.2 Experiment 6: Results

6.2.1 Analysis of Reaction Times

There were no outliers in this data. The ordering of the means are as predicted (and can be seen in Table 33 below) with the exception of 3 (3:1) incompatible properties and 2 (2:2) incompatible properties. However, the range of the mean RTs is a lot smaller than that found in Experiment 5 (25ms here compared to 59 in Experiment 5). It is thought that this might be due to the dampening of the compatibility effect by using arbitrary shapes compared to arrows that are thought to have stronger S-R associations with a directional response.

Number of incompatible flankers (ratio)	Mean RT	SD
0 (0:4)	422	37.6
1 (1:3)	430	35.5
3 (3:1)	435	32.2
2 (2:2)	442	40.3
4 (4:0)	447	40.8

Table 33. Mean RTs (ms) in ascending order for all conditions

A One Way Repeated Measures ANOVA (with 5 levels of number of incompatible properties 0-4) revealed that there is a significant difference between these means [$F(4, 44) = 7.12$; $ms_{error} = 157.983$; $p < 0.000$] and a series of Tukey tests were performed to determine where the significant differences lie and the outcome of these analyses can be seen in Table 34 below.

	0 (0:4)	1 (1:3)	2 (2:2)	3 (3:1)
1 (1:3)	q = 2.22 p > 0.05	*	*	*
2 (2:2)	q = 5.38 p < 0.05	q = 3.16 p > 0.05	*	*
3 (3:1)	q = 3.67 p > 0.05	q = 1.45 p > 0.05	q = 1.72 p > 0.05	*
4 (4:0)	q = 6.83 p < 0.05	q = 4.61 p < 0.05	q = 1.44 p > 0.05	q = 3.16 p > 0.05

Table 34. Differences between each condition

The results of the post hoc analyses revealed that the 4 (4:0) incompatible properties condition generated significantly longer RTs than the conditions with 0 (0:4) and 1 (1:3) incompatible properties. The analysis also found that the 2 (2:2) incompatible properties condition significantly differed from the 0 (0:4) incompatible properties condition.

There are no other significant differences, but it is thought that this is because again the differences are dampened down due to weaker S-R associations. We already know that arrows have greater propensity to generate the compatibility effect (by comparing Experiments 3 and 4) but there might also be another reason why the range of the means is quite small.

A potential problem with this design is that colour and shape information may be processed at different rates or generate different strengths of activation. Some theorists (see Glaser & Glaser, 1982, in section 1.13 for instance) argue that there

are different speeds of processing between stimulus dimensions (in this case shape and colour information) and this might also be responsible for dampening the compatibility effect. Furthermore, Barber and O'Leary (1997) and Lu (1997) argue that the activation strength and/or speed can vary according to the S-R associative strength amongst other things.

If colour and shape are processed at different rates, the dimension that is processed fastest should provide activation to the corresponding response channel before that generated by the other dimension. Similarly, if the colour and shape dimensions generate different activation strengths, then, the dimension that produces the strongest activations would have a greater propensity to affect responding. For this reason, it is important to examine whether there are any differences in RTs between conditions with 1 incompatible shape compared to 1 incompatible colour and conditions with 2 incompatible shapes compared to 2 incompatible colour conditions.

If there is a difference between the colour and shape dimensions' propensity to affect responding, then there may be a crossover effect whereby the incompatible and compatible properties would only partially cancel each other out. That is, the facilitative effects of say 2 compatible flankers would not necessarily equal the slowing effects of 2 incompatible shapes. Further complications are expected if the dimensions differ in both their processing speeds and the strength of activations generated. The idea of a crossover effect might account for the unexpected result

found above that showed that 3 (3:1) incompatible properties within an array generated faster RTs than 2 (2:2) incompatible properties (although this difference was not significant).

6.2.2 Differences Between the Colour and Shape Dimensions in RTs

The mean RTs for 1 incompatible colour and 1 incompatible shape trials are given below in Table 35. To check for consistency the means for 2 incompatible colour and 2 incompatible shape trials are also presented.

Condition	Mean RT	SD
1 Incompatible Shape	421	35.2
1 Incompatible Colour	439	38.2
2 Incompatible Colours	439	41.7
2 Incompatible Shapes	447	65.3

Table 35. Mean RTs (ms) in ascending order for 1 or 2 incompatible shape or colour conditions

A Paired T test was conducted on the mean RTs for trials that contained 1 incompatible colour and 1 incompatible shape to see if there is a difference in their propensity to slow RTs. The T test revealed that there is a significant difference between the RTs for 1 incompatible colour trials and 1 incompatible shape trials [$T(11) = 3.23$; $p < 0.01$]. That there is a difference between trials with 1 incompatible colour and 1 incompatible shape suggests that colour and shape do not have the same propensity to affect responding.

In order to determine which of the two dimensions has the greater propensity to affect responding, one must look at the residual flanker properties that would contribute to the difference in accumulated activation strength. In the 1 incompatible shape trials, the other flanker properties are a compatible shape and 2 compatible colours. If the activations generated from the compatible and incompatible shapes cancel each other out, (assuming that the activations generated by an incompatible shape and a compatible shape are equal), then, the 2 compatible colours are left over to facilitate responding. Similarly, the 1 incompatible colour condition also presents 1 compatible colour and 2 compatible shapes. Again the incompatible colour and compatible colour properties should cancel each other out leaving the 2 compatible shapes to facilitate responding. Thus, the locus of the difference in RT between 1 incompatible shape and 1 incompatible colour trials should be due to the 2 compatible colour properties seen in 1 incompatible shape trials and the 2 compatible shape properties seen in the 1 incompatible colour trials. That is, the locus of the effect should lie in the ability of the residual compatible flanker dimensions to facilitate responding.

Using this logic, we can assume that the colour has the greater propensity to affect responding because the RTs for the 1 incompatible shape trials were faster than that for the 1 incompatible colour trials. This suggests that 2 compatible colours have a greater propensity to facilitate responding compared to 2 compatible shapes. However, it is not possible to determine whether the colour dimension has a greater

propensity to affect responding due to it having a stronger activation strength or quicker activation compared to the shape dimension.

To check for consistency, possible differences between 2 incompatible colour trials and 2 incompatible shape trials were also compared. If colour does have a larger propensity to affect responding, then we would expect to see the 2 incompatible colour trials producing longer RTs than the 2 incompatible shape trials. This is because the facilitative effects should outweigh the interference effects in the 2 incompatible shape trials and the interference effects should outweigh the facilitative effects in the 2 incompatible colour trials. Therefore, the 2 incompatible colour trials should produce slower RTs than the 2 incompatible shape trials. However, the mean RTs for the 2 incompatible shape trials and 2 incompatible trials are presented in Table 35 and are not consistent with the idea that the colour dimension has a greater propensity to affect responding. A Paired T test revealed that there was no significant difference [$T(11) -0.43$; $p > 0.05$].

However, the difference between the 2 incompatible shape conditions and the 2 incompatible colour conditions should be smaller than the difference between the 1 incompatible shape and 1 incompatible colour condition because the effects of the 2 incompatible properties conditions should be partially overridden by the 2 compatible properties also within the stimulus array. Furthermore, the SD for the 2

incompatible shape condition is fairly large and might be partially responsible for the order of the means.

Another problem is that there are no predictions made in terms of whether the activation strength of the target varies across conditions. It might be, for instance, that the activation strength assigned the target might vary as a function of the difficulty in making a correct response. Thus, the extent to which flanker properties might affect responding does not necessarily increase in terms of a linear function. Thus, there may be diminishing returns in terms of flankers' propensity to affect responding as a function of response difficulty. However, if the activation strength of the target is mediated according to the difficulty of making a response, then, we would not really expect to see differences between compatibility conditions per se as the activation strength assigned to the target should compensate for the differences between conditions. A more likely scenario then, is that the activation strength assigned the target is mediated before the stimulus presentation (in terms of a predictive judgement for example).

6.2.3 Analysis of Errors

The ordering of the percentage of errors is as predicted with the exception of 3 (3:1) and 4 (4:0) incompatible properties (see Table 36 below). There were 11.6% outliers in this data and they were replaced with the highest value for that condition that was not an outlier.

No. of Incompatible Flankers (ratio)	Mean % age	SD
0 (0:4)	2.6	1.8
1 (1:3)	2.9	2.0
2 (2:2)	3.8	3.2
4 (4:0)	4.4	1.8
3 (3:1)	5.0	3.3

Table 36. Mean percentage of errors in ascending order for all conditions

A Repeated Measures ANOVA revealed a significant main effect of condition [$F(4, 44) = 3.925$; $m_{\text{error}} = 3.273$ $p < 0.01$]. A series of Tukeys were performed to see where the significant differences lie and these can be seen in Table 37 below. The post hoc analysis shows that flankers that have 3 (3:1) incompatible properties within them differ from when there are 0 (0:4) and 1 (1:3) incompatible properties within them.

	0	1	2	3
1	q = 0.49 p > 0.05	*	*	*
2	q = 2.36 p > 0.05	q = 1.87 p > 0.05	*	*
3	q = 4.67 p < 0.05	q = 4.18 p < 0.05	q = 2.31 p > 0.05	*
4	q = 3.54 p > 0.05	q = 3.05 p > 0.05	q = 1.18 p > 0.05	q = 1.13 p > 0.05

Table 37. Differences in percentages of errors between the conditions

That 3 (3:1) incompatible properties and not 4 (4:0) incompatible properties significantly differs from 1 (1:3) and 0 (0:4) incompatible properties conditions is not

quite as expected and again this might be due to some cross over effect assuming that the activations generated by colour and shape dimensions may differ either in terms of the activation strength or speed or both. However, it is very hard to determine this from the data, given that no predictions are made concerning whether the activation strength assigned the target is static across all conditions or not.

6.2.4 Discussion

Experiment 6 has found some evidence that the activations generated by different stimulus dimensions are pooled and that the difference in accumulated activation mediates the extent of response slowing. This is because the ordering of the mean RTs were consistent with the predictions made by the AASD model (with the exception of the 3 (3:1) incompatible properties condition). However, not all the differences were significant and the range of the RT means was quite small. This suggests that there is some noise in the data. It is thought that the noise might be due to differences in the propensities of the colour and shape dimensions to affect responding (there was some evidence that the colour dimension had a stronger propensity to affect responding than the shape dimension) but an examination into this was inconclusive.

It is thought that the effects here might also have been damped down by having to use stimuli that did not have strong intrinsic associations with the required response. However, using stimuli that have a strong S-R association might bias the results in

terms of inducing differences between the stimulus dimensions in their propensity to affect responding. This is because previous theorists argue that stimuli that have strong S-R associations generate faster and stronger activations compared to stimuli that do not have strong S-R associations.

Furthermore, Experiment 6 also found that the patterns of errors tend to mirror that of the RT data although in both cases the 3 (3:1) incompatible properties conditions is out of synchronisation with the other means. This offers partial support for the idea that the probability of making an error increases as the difference between activations in the correct and incorrect response channels decreases.

Chapter 7

General Discussion and Conclusion

7.1 The AASD model

The present research extended the Continuous Flow Model (Eriksen & Schultz 1979) in an attempt to account for not only the compatibility effect observed in the flanker task, but also the pattern of errors in responding and the inconsistencies between flanker tasks and letter detection tasks in terms of whether compatible flankers have a facilitative effect on responding. There are some convincing models (see section 2.3) that account for all types of compatibility and how task relevant and irrelevant information and information from any stimulus dimension can affect responding. However, these models do not take into account the inconsistencies between the redundancy gain and flanker tasks in terms of whether compatible flankers facilitate responding or not.

The AASD model is not intended to be an alternative to these comprehensive models. The AASD model only offers scope to explain how different types of compatibility may come about rather than explicitly incorporating a mechanism to account for these effects. Rather the AASD model is merely an extension of the Continuous Flow model that would enable it to account for not only the compatibility effect, but also the pattern of errors in responding and also the inconsistencies between whether compatible flankers facilitate responding or not.

7.2 Differences in accumulated activation strengths

The AASD generated a number of predictions of the ordering of the means for compatibility conditions based on assumed differences in accumulated activation strengths between competing response channels. In doing so, the model predicted that the effects of compatible and incompatible flanker properties would cancel each other out. The strongest evidence for this was found in Experiment 4, which showed that mixed flanker trials (which presented an equal number of compatible and incompatible flankers within a stimulus array) generated faster RTs than incompatible flanker trials.

Some might argue that there was less response slowing for the mixed condition compared to the incompatible condition because there were simply more incompatible flankers in the incompatible condition. If this was the case, then we would expect to see slower RTs for incompatible conditions that contained 6 flankers compared to when there were 4 or 2 flankers. There was no evidence found that increasing the number of incompatible flankers generated longer RTs when looking at the incompatible conditions that contained either 2, 4 or 6 flankers in Experiments 3 and 4. Indeed Experiments 3 and 4 found an unexpected pattern in the ordering of the mean RTs for each compatibility condition across the number of flanker conditions. That is, Experiment 3 found that RTs increased for each compatibility condition as the number of flankers went from 2 to 6 and then to 4 flankers and Experiment 4 found that the RTs increased as the flankers went from 4

to 6 and then to 2 flankers. However, there was no significant main effect of number of flankers or interaction between the number of flankers and the compatibility conditions.

However, there is a problem with comparing compatibility conditions across the number of flanker conditions. One obvious problem is the difference between the number of stimuli that are available for processing. If one assumes capacity limitations, then we might expect to see that the RTs would be longer for 6 flanker conditions compared to 4 and 2 flanker conditions. Experiment 1 found just this, but there was no compatibility effect found in Experiment 1. This suggests that the properties of the flankers in Experiment 1 were not adequately processed and it is thought that this was because the participants had not developed strong S-R mappings due to them not performing many trials. This claim is supported when comparing Experiments 1 and 2.

There is also evidence to suggest that when flankers are presented in a linear array, the number of flankers presented within that array does not influence performance (Eriksen & Eriksen 1974 for example). Thus, we would therefore not expect to see any differences between the incompatible conditions with 2, 4 or 6 flankers. Perhaps this might be explained by assuming that the activation strength of the target is altered to compensate for the differences in processing demands (like the zoom lens metaphor of attention). Furthermore, previous research (discussed in section 1.15)

has shown that flankers that are at further eccentricities from the target have less effect on responding compared to those closer to the target. This is in line with the gradient metaphor of attention. Thus, we would expect to see diminishing returns as the number of flankers increases. There was no evidence found in Experiments 1-4 that the propensity of flankers to affect responding decreased at further eccentricities from the target.

Other problems associated with comparing compatibility conditions across the number of flankers conditions is that the perceptual load of the task has been found to mediate whether irrelevant (to-be-ignored) information is processed (mentioned in section 1.15). Lavie and her colleagues found that if the perceptual load of the task is sufficiently high, irrelevant information could be ignored. It might be that there is higher perceptual load when there are more flankers (although participants are instructed to ignore the flankers and therefore, they should not theoretically add to the perceptual load of responding to the target). There was no evidence to suggest that increasing the number of flankers increased the perceptual load of the task sufficiently for the flankers to be ignored. If this were the case we would expect to see no compatibility effect for conditions where there were 6 flankers.

7.3 The ratio of compatible to incompatible properties

Evidence that incompatible and compatible flanker properties cancel each other out was obtained in Experiments 5 and 6. Experiments 5 and 6 showed that the ratio of

compatible to incompatible flankers properties mediates the extent of response slowing (compared to the ceiling level found in compatible flanker trials). It was found that responses were slower with higher ratios of incompatible to compatible flankers compared to smaller ratios of incompatible to compatible flankers and it was thought that this is a result of both facilitation from compatible flankers and response slowing from incompatible flankers.

The strongest evidence that supports the view that compatible and incompatible flanker properties cancel each other is generated in Experiments 4 and 5. Experiment 4 showed that the mixed compatible and incompatible condition generated faster RTs and fewer errors than the incompatible condition. Experiment 5 showed that the ratio of compatible to incompatible flankers mediates RTs and percentages of errors in responding. In both cases, it is hard to delineate whether the differences are due to either: an additive effect of the number of incompatible flankers (i.e. the more incompatible flankers there are, the slower responding will be), or whether it is due to facilitative effects associated with the compatible flankers (due to the problems associated with examining the compatibility conditions across the number of flanker conditions).

7.4 Inconsistencies between redundancy gain and flanker task studies

The AASD model offers an explanation as to why compatible flankers only seem to facilitate responding in the presence of incompatible and/or neutral flanker

properties. The AASD model maintains that responding is at ceiling level in the absence of incompatible or neutral flanker properties as there is no response competition. Thus, the certainty that the most activated response is the correct response is immediate and there should be no difference in compatible flanker trials when there are different numbers of compatible flankers. Experiments 1-4 found no evidence of facilitative effects associated with additional compatible flankers (by comparing compatible flanker trials with 2, 4 and 6 flankers) in terms of them enhancing reaction time per se. However, because of the problem associated with comparing compatibility conditions across the number of flanker conditions, we have to be careful about drawing conclusions on the basis of these findings.

7.5 The activation strength of the target

It is thought that the activation strength assigned the target is larger than that generated by an individual flanker. The activation strength assigned to the target was the number of flankers plus one to ensure that the activation in the correct response channel exceeds that of the incorrect response channel (under ideal conditions). This was to ensure that the AASD model predicted that the correct response would be made a majority of the time. However, it is not known whether the assignment of the activation strength of the target varies across the number of flanker conditions or across the compatibility conditions or indeed whether the activation strength of the target is static across all conditions.

However, if the activation strength of the target is static across all conditions, we would expect to see an interaction between the number of flankers and the compatibility conditions, as a greater compatibility effect would be expected for 6 flanker conditions. This is because the difference between the accumulated activation strengths across the compatibility conditions would be greater for 6 flanker conditions compared to when there are fewer flankers (see section 4.1 for the calculations of the predictions). This was not the case. It is more likely then, that the activation strength of the target is variable. It might, for instance, vary to compensate for the amount of processing that is required. There may be a trade off between processing irrelevant information against the efficiency of processing target information or in making a response (like Lavie's perceptual load theory).

Furthermore, we know that it is possible to select information that has the greatest utility in making a response from studies that have found that only task relevant information (or information from task relevant dimension) affects responding to target information (see section 1.13, de Fockert, Rees, Frith and Lavie 2001; Maruff, Danckert, Camplin & Currie 1999 for examples). The uncertainties about how the weighting of activation strength is assigned, therefore, poses another problem when looking at the compatibility conditions across the number of flanker conditions. However, no interactions between these conditions and no significant differences between the number of flankers conditions were found (with the exception of Experiment 1).

7.6 Patterns of errors in responding

Concepts of response certainty and variability taken from SDT were incorporated into the AASD model that allowed for predictions to be made for the ordering of the means in terms of the percentage of errors across the compatibility conditions. Previous studies (see section 1.11) have reported that the pattern of errors in responding mirrors that of the RT data and there is also support for this here. That is, there were higher percentages of incorrect responses for incompatible conditions compared to compatible conditions.

This AASD model also predicted, however, that as the ratio of incompatible to compatible flankers increases, so does the probability of making an incorrect response and again there is evidence to this effect observed here in that Experiment 4 found that the mixed (compatible and incompatible flankers) generated fewer errors than the incompatible condition for 4 and 6 flanker conditions. Furthermore, Experiment 5 found that the ratio of incompatible to compatible flankers mediates the percentages of errors made in responding, although, not all of the differences were significant. Thus, the AASD model was successful in accounting for the patterns of errors observed.

7.7 More than one stimulus dimension

The AASD model is designed primarily to account for pooled activation from one stimulus dimension, although it offers scope to account for how information from

more than one dimension affects responding. The AASD model assumes that information that can be associated with a response in any way, goes on to prepare that response. This includes information from different stimulus dimensions as well as aspecific activation generated from task irrelevant information that may be associated either with a response or that has associations with response stimuli (a good example of this is the correlational cuing paradigm by Miller 1987 and 1998).

The notion that information from different dimensions is combined to prime a response is consistent with the AP model proposed by Fournier, Eriksen & Bowd (1998) that assumed that all object features are processed independently and in a parallel fashion. Each feature is thought to prime its task relevant response and information from different stimulus features are thought to be combined. Other models are able to account for information from more than one stimulus dimension in terms pathways of activations between features/elements that have something in common (see DO 97 model described on section 2.3).

Many studies have found that irrelevant stimulus properties can affect responding to information in a relevant stimulus property ('*relevant*' here refers to information that has some utility in making a response and is specified in the task instructions). The Stroop and Simon effects are good examples of this, but there are many other examples given in the introduction (see 1.13 and 1.9). The AASD model predicts that compatible and incompatible flanker properties would cancel each other out (i.e.

add nothing to alter the difference in accumulated activation strength difference) if they have the same activation strengths and speeds (and providing they both have the same significance/utility in making a response – see Maruff, Danckert, Camplin and Currie 1999). Thus, the AASD predicted that compatible and incompatible information from different stimulus dimensions should cancel each other out if they have the same propensity to affect responding.

In order to see whether compatible and incompatible flanker properties across different stimulus dimensions cancel each other out, Experiment 6 examined whether the ratio of compatible to incompatible flanker properties presented in both colour and shape dimensions, mediate the extent of response slowing. Some evidence was found that a higher ratio of incompatible to compatible instances generated slower and less accurate responding compared to smaller ratios of incompatible to compatible flanker properties. However, the results were less clear cut than when only one stimulus dimension was used and it is thought that this is because of possible differences in either the activation strengths or speeds of processing between the two stimulus dimensions.

Another reason why the results were not clear-cut may be because the stimulus dimensions used were shape and colour. It has already been established that shapes have a smaller propensity to generate the compatibility effect than arrows (by comparing Experiments 3 and 4 with Experiments 1 and 2). Arrows could not be

used, however, because it was thought that using arrows would automatically bias the results in favour of the shape dimension having a greater propensity to affect responding than the colour dimension due to arrows having a strong S-R association. Arbitrary shapes were therefore thought to have more equality with the colour dimension in terms of the strength and/or speed of activation strength generated. Perhaps future research might artificially manipulate the S-R associations across different stimulus dimensions to test this theory.

There was some evidence in Experiment 6 for a crossover effect where for both the RT and the percentage of errors data, the condition with 3 incompatible instances is out of synchronisation with the predicted ordering of the means. It was thought that this may be due to the colour and shape dimensions having different propensities to affect responding in terms of either the activation speeds and/or strengths. There are a number of reasons for this. Firstly, there were always only two flankers in all conditions so there should not be any variability in terms of processing resources according to the amount of information being processed. Furthermore, there was no crossover in Experiment 5, which also held the number of flankers constant across the conditions. On further scrutiny of the differences between the colour and shape dimensions in Experiment 6, some evidence was found that supports the idea that the colour dimension has a greater propensity to affect responding compared to the shape dimension.

That the AASD model assumes that activation from different stimulus dimensions may have different propensities to affect responding either in terms of their activation strengths or speeds, seems to adopt an elemental theory of information processing. That is, information from different stimulus/object dimensions are processed separately. There is evidence that individual stimulus/object features are processed separately, (Lavie 1997 is a good example) but this is no cause to reject the idea that objects, and the elements and features of objects, are processed as a whole as configural learning theorists suggest. Indeed we tend to conceptualise individual stimulus elements as a whole. It may be possible to process stimulus/object information both as conjoined features as well as processing the individual elements separately. Indeed, Fanselow (1999) suggested that both elemental and configured stimuli processing systems interact. Also, it may be the case that the conjunctions between stimulus features are made at some stage in processing either pre or post-attentive.

Recent studies (Fournier, Scheffers, Coles, Adamson & Abad 2000; Smid, Bocker, van Touw, Mulder & Brunia 1996 and Smid, Jacob & Heinze 1997) have found evidence that partial information about individual stimulus features is available in advance of information about fully conjoined multidimensional information about a stimulus. Fournier et al (2000) for example, suggest that response priming may occur based on accumulated activations of partial information of combined stimulus features.

The AASD model, however, assumes that feature information does go on to prepare a response even before a response decision is made. This is not the same as saying that feature information prepares a response before the target identity is achieved. Furthermore, a response may not even be executed on the basis of the target identity. In some cases we may make an error in responding even though we know the identity of the target. The feeling of knowing that you have made an incorrect response immediately after executing the response demonstrates this. This seems to suggest that response execution is based on response channel activations rather than completed stimulus evaluation processing or on the known identity of the target stimulus. On the other hand, however, these errors may be explained in terms of faulty S-R pairings. Either way, response execution does not necessarily have to be based on a decision about the target identity and may be automatically triggered by a threshold value of activation being reached rather than a controlled cognitive decision (as strict discrete stage theorists argue).

7.8 Different types of compatibility

There are many different ways in which task irrelevant and to-be-ignored information affect responding and Kornblum, Hasbroucq, & Osman, (1990) produced taxonomy of all the S-R, S-S and combinations of S-R and S-S compatibility effects. It is not difficult to see how the AASD model might also be used as a framework to account for different types of compatibility, given that the AASD model makes the

assumption that information that can be related to a response in any way can go on to prepare a response.

It may be possible to use the AASD model to predict the ordering of the means for these different compatibility types providing that the differences between stimulus dimensions in terms of their propensity to affect responding (speed and strengths of activation), and the strength of the S-R associations are known, so that possible cross over effects may be determined. However, the perceptual load of the task should also be taken into account as Lavie and colleagues have shown that this affects the extent to which irrelevant information affects responding.

7.9 Inhibition of responding

The AASD model differs from the Continuous Flow model in that it rejects the notions of mutual inhibition and response execution being based on a static threshold level of activation being reached. Instead, it draws on more recent claims and concepts from SDT that suggest response execution is based on variable thresholds of activation. In doing so, the AASD model predicts that the ratio of compatible to incompatible flanker properties would mediate the extent of response slowing. The Continuous Flow model is unable to account for these graded effects because it assumes that the compatibility effect is merely based on mutual inhibition – that is, under conditions where there is response competition, both (or all) response channels are inhibited from making a response.

However, although the AASD model does not incorporate inhibition explicitly into the model, the notion of inhibition is not entirely rejected. Indeed, negative priming studies (mentioned in section 1.16) provide strong evidence that inhibition does occur, at least for previously to-be-ignored information. In line with other theorists, the AASD model has suggested that the activation strength of the target is enhanced compared to the flankers (there are a number of reasons put forward for this enhancement – the target being in the correct spatial location, the target being the focus of attention and it also having the greatest utility or relevance in performing the task effectively). However, perhaps we could do away with the notion that the activation generated by the target is enhanced in favour of arguing that the activation generated by the flankers or irrelevant information is inhibited in order to retain the significance of the target. Indeed, recent papers have suggested that inhibition is a reactive process in that greater flanker activation requires more inhibition (Fox 1994, 1998; Houghton, Tipper, Weaver & Shore 1996, for example).

It is also possible that the activation of the target is enhanced in relation to the flankers and also that the activation generated by the flankers is inhibited. There may also be a trade-off between the enhancement of the target and the degradation of flankers, if one assumes capacity limitations. Indeed a recent paper by de Fockert, Rees, Frith & Lavie (2001) proposed that the availability of working memory resources plays a role in the extent to which distractors affect responding. Furthermore, Lavie & Fox (2000) examined the effect of perceptual load on

inhibition. Specifically they examined the amount of inhibition of irrelevant distractors in a negative priming study. They concluded that.....

“Selective attention involves (at least) two modes of selective attention: a passive selection mode, in which selective processing occurs as a natural consequence of exhausting available capacity in situations of high perceptual load, and an active selection mode, which allows for selective behavior by actively inhibiting competing response tendencies from the irrelevant stimuli when these are fully processed (i.e., only in situations of low perceptual load).” p1050

It is thought that a trade-off is the most likely scenario as real life experiences give us the feeling that we can adjust our attentional resources to include or exclude peripheral information as we judge appropriate.

7.10 Variable threshold

The AASD model incorporates concepts from signal detection theory and recent ideas in terms of there being a variable activation threshold for triggering a response (Houghton & Tipper 1994; and Barber & O’Leary 1997 for examples). The idea of a variable threshold is a persuasive development as it allows scope for explaining differences between expected RTs for tasks that vary in difficulty. Tasks that are more difficult may have higher thresholds to trigger a response (due to the higher

load of stimulus processing, more transformations needed between a stimulus and a response or due to high confusability between stimuli, for example) whereas lower thresholds may be set for triggering a response in easier tasks. Thus, we would expect more difficult tasks to generate longer RTs compared to easier tasks. This can be seen by comparing Experiment 1 and 2 where RTs in Experiment 2 are presumed to be quicker than those in Experiment 1 due to the participants having developed strong S-R association by conducting more trials.

7.11 Speed and accuracy trade off

The notion of a variable threshold also has an advantage over static thresholds because it provides scope to account for the mechanisms behind speed accuracy trade offs (SAT). Varying the criteria for making a response allows us to see more clearly how judgments can be made in terms of assigning importance to SAT decisions. A higher threshold may be set for responding when accuracy is the priority compared to speed and vice versa. Adopting a dynamic threshold that may vary as a function of task difficulty or SAT seems to offer better scope for interpreting differences across task parameters.

Furthermore, we know that the SAT can be manipulated in terms of the importance assigned to speed or accuracy in the task instructions (see speed-stress research paradigms for example, Wickelgren 1977, and Wood & Jennings 1977 which show that accuracy increases as the amount of time allowed for processing stimuli also

increases) and therefore the value attached to speed or accuracy may be subjective. Any model that suggests a variable threshold value for response execution therefore has a greater scope in being able to account for SAT. A subjective speed accuracy trade-off may also account for variability between subjects' performance in terms of differences between RT and accuracy and may account for some of the variability observed in these variables.

It is possible to see how the AASD model may be extended to account for speed accuracy trade-offs (SAT). The AASD model makes assumptions about the probability of making an incorrect response based on the difference in accumulated activation strength between competing response channels and there is some support for these predictions offered here in this research. However, the AASD model also assumes that as time of processing increases, so does the difference between the accumulated activation strengths between competing response channels. Thus, it may be fair to suggest, that as time of processing increases, the likelihood of making an incorrect response decreases (see for instance Smid, Mulder & Mulder 1990, who found that early responses are more inaccurate when the flankers are incompatible rather than compatible).

One has to be careful about talking about SAT across conditions though. Within each compatibility condition we might expect either fast and erroneous responding, or slow and accurate responding due to possible SAT. However, the notion of SAT

seems to break down when you look at accuracy and RT data across compatibility conditions. What we tend to find is that the conditions that generate the fastest responding (the compatible conditions or the conditions with a smaller ratio of incompatible to compatible flanker properties) also seem to be more accurate. Conversely, conditions that generate the slowest RTs (such as incompatible trials or trials with higher ratios of incompatible to compatible flanker properties) also tend to generate higher percentages of errors. Thus, SAT can only be predicted within each compatibility condition and not across compatibility conditions.

7.12 The problem of neutral flankers

The AASD model is incomplete in that it does not attempt to account for neutral flankers or for go – no go tasks, which, sometimes require that no response is made. Previous research (see section 1.4) has shown that neutral flankers have an intermediate effect on responding compared to compatible and incompatible flanker conditions. There are 3 possible ways that neutral flankers can affect responding. They can either affect responding by taking up processing resources that might be utilised in processing task relevant information, they might be contributing to the activation in the correct or incorrect response channels (although by definition this should not happen because neutral flankers should not have any association with a correct or incorrect response channel), or they might be contributing to an independent response channel (a no response channel for example). It is not clear which of these possibilities is most likely.

However, there must be a mechanism that allows responses to be withheld. The go – no go task, for example, requires that no response be made to trials where there is an absence of the target stimulus. It might be fair to argue then, that there is some sort of a no response channel. The research chose to study only compatible and incompatible flankers because it requires that only a correct and incorrect response channel be examined. Future research in the development of the AASD model would need to examine how neutral flankers affect responding.

7.13 Continuous versus discrete stage models

Continuous Flow and activational models like the AASD model have the advantage over discrete stage models as they reduce the complexity needed to predict behaviour in that they do not have to incorporate stages. The AASD model here is simple in that it does not incorporate stages (like those adopted by discrete stage theorists), in terms of responses being based on a decision stage or a matching stage between the stimulus and template stages in order to check that S-R mappings are correct. In reducing the complexity though, such models paint a grim view of human functioning in terms of viewing humans in the behavioural sense in that we simply respond to the external world automatically and do not have to act upon the information in order to perform adequately.

However, we can take solace in the inadequacies of the model. Whether we actively control our attentional resources or whether they are determined by situational

factors has not been answered and this leaves scope to see humans having control over their environment. That we can assign value to the relevance of information and use this to guide responding is evidence of this (de Fockert, Rees, Frith & Lavie 2001 and Maruff, Danckert, Camplin & Currie 1999).

7.14 Conclusion

This research offers an extension of the Continuous Flow model which can account theoretically for the additivity of compatible and incompatible flanker properties and the inconsistencies as to whether compatible flanker properties have a facilitative affect on responding or not as well as the patterns of errors in responding. The AASD model also offers scope to account for how information from different stimulus dimensions and task irrelevant information affects responding. It may also be able to account for different types of compatibility once the hierarchy of different flanker properties in terms of their propensities to affect responding (in terms of S-R association, salience, relevance and S-S associations) has been determined.

However, the AASD model is incomplete as it does not attempt to account for neutral flanker properties and more experimentation is needed to be able to delineate compatible flanker properties facilitation with the response slowing of incompatible flanker properties. Furthermore, experimentation is needed to assess whether the activation strength assigned to the target is static or what criteria may be responsible for assigning its value. It is thought that the model may also need to include

inhibition as there is evidence from negative priming studies that to-be-ignored information is inhibited at some point. Inhibition may take place before or after response execution and there may also be a trade off between the target facilitation and flanker inhibition.

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Appendices

Statistics Summary Tables

All of the analyses were conducted using ExperStat 2.2a Beta at Nottingham University. ExperStat allows post hoc tests to be conducted for within subject's designs and the Tukey (HSD) test was used for the post hoc analysis conducted here.

Experiment 1

Analysis of the RT data:

Analysis of Variance Summary Table

Data from explflankers.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p	
Subjects	4414903.206	83	53191.605			
A (flanker)	51325.855	2	25662.927	5.452	0.0051	**
(Error AxS)	781309.100	166	4706.681			
B (cond)	6242.537	5	1248.507	1.675	0.1393	
(Error BxS)	309241.131	415	745.159			
AB	5620.493	10	562.049	0.670	0.7534	
Error ABxS)	696733.223	830	839.438			

Tukeys for the differences between the number of flanker conditions.

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of flanker

2	vs 4	q =	1.05	
2	vs 6	q =	4.47	**
4	vs 6	q =	3.41	*

Experiment 2

Analysis of the RT data:

Analysis of Variance Summary Table

Data from exp2rt.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	237259.099	11	21569.009		
A (flanker)	386.241	2	193.120	0.146	0.8650
(Error AxS)	29101.328	22	1322.788		
B (cond)	3434.829	3	1144.943	6.915	0.0010 ***
(Error BxS)	5463.873	33	165.572		
AB	1676.408	6	279.401	2.178	0.0561
(Error ABxS)	8467.619	66	128.297		

Tukeys for the differences between the compatibility conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Comparison between levels of condition

comp	vs incomp	q =	1.54	
comp	vs mix	q =	6.02	**
comp	vs neut	q =	1.28	
incomp	vs mix	q =	4.48	*
incomp	vs neut	q =	0.26	
mix	vs neut	q =	4.75	*

Analysis of the Error data:

Analysis of Variance Summary Table

Data from exp2err.txt
 Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	1618.556	11	147.141		
A (flanker)	11.139	2	5.570	0.270	0.7662
(Error AxS)	454.452	22	20.657		
B (cond)	25.127	3	8.376	2.076	0.1223
(Error BxS)	133.136	33	4.034		
AB	77.135	6	12.856	2.430	0.0349 *
(Error ABxS)	349.180	66	5.291		

Tukeys of the interaction between the number of flankers and the compatibility conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

at level 2 flankers

COMP	vs INCOMP	q =	5.38	**
COMP	vs MIXED	q =	2.37	
COMP	vs NEUTRAL	q =	2.13	
INCOMP	vs MIXED	q =	3.00	
INCOMP	vs NEUTRAL	q =	3.25	
MIXED	vs NEUTRAL	q =	0.24	

at level 4 flankers

COMP	vs INCOMP	q =	0.73
COMP	vs MIXED	q =	0.53
COMP	vs NEUTRAL	q =	1.72
INCOMP	vs MIXED	q =	1.26
INCOMP	vs NEUTRAL	q =	2.46
MIXED	vs NEUTRAL	q =	1.19

at level 6 flankers

COMP	vs INCOMP	q =	2.70
COMP	vs MIXED	q =	0.06
COMP	vs NEUTRAL	q =	2.82
INCOMP	vs MIXED	q =	2.64
INCOMP	vs NEUTRAL	q =	0.11
MIXED	vs NEUTRAL	q =	2.76

Experiment 3

Analysis of the RT data:

Analysis of Variance Summary Table

Data from exp3rt.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	249155.497	9	27683.944		
A (flanker)	5586.298	2	2793.149	2.416	0.1177
(Error AxS)	20813.904	18	1156.328		
B (cond)	3938.138	3	1312.713	10.355	0.0001 ***
(Error BxS)	3422.940	27	126.776		
AB	305.363	6	50.894	0.322	0.9227
(Error ABxS)	8534.567	54	158.048		

Tukeys for the differences between the compatibility conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of cond

comp	vs incomp	q =	7.06	***
comp	vs neut	q =	2.47	
comp	vs mix	q =	5.85	**
incomp	vs neut	q =	4.60	*
incomp	vs mix	q =	1.21	
neut	vs mix	q =	3.39	

Analysis of the Error data:

Analysis of Variance Summary Table

Data from exp3err.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	1299.139	9	144.349		
A (flanker)	19.339	2	9.669	2.124	0.1485
(Error AxS)	81.935	18	4.552		
B (cond)	140.433	3	46.811	8.163	0.0005 ***
(Error BxS)	154.838	27	5.735		
AB	38.367	6	6.395	1.695	0.1400
(Error ABxS)	203.699	54	3.772		

Tukeys for the differences between the compatibility conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of cond

comp	vs incomp	q =	5.95	**
comp	vs neut	q =	0.05	
comp	vs mix	q =	2.89	
incomp	vs neut	q =	6.01	**
incomp	vs mix	q =	3.06	
neut	vs mix	q =	2.94	

Experiment 4

Analysis of the RT data:

Analysis of Variance Summary Table

Data from exp4rt.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	401072.000	11	36461.091		
A (flanker)	6715.984	2	3357.992	0.534	0.5938
(Error AxS)	138416.763	22	6291.671		
B (cond)	53187.799	3	17729.266	40.747	0.0000 ****
(Error BxS)	14358.349	33	435.101		
AB	574.646	6	95.774	0.778	0.5904
(Error ABxS)	8129.478	66	123.174		

Tukeys for the differences between the compatibility conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of cond

comp	vs incomp	q =	13.83	***
comp	vs neut	q =	0.64	
comp	vs mix	q =	5.44	**
incomp	vs neut	q =	13.20	***
incomp	vs mix	q =	8.40	***
neut	vs mix	q =	4.80	**

Analysis of the Error data:

Analysis of Variance Summary Table

Data from err4out.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	6383.982	11	580.362		
A (flanker)	258.439	2	129.220	3.182	0.0611
(Error AxS)	893.306	22	40.605		
B (cond)	2641.116	3	880.372	13.350	0.0000 ****
(Error BxS)	2176.183	33	65.945		
AB	154.886	6	25.814	3.662	0.0034 **
(Error ABxS)	465.203	66	7.049		

Tukeys to examine the differences between all conditions

Comparisons Between Means for Selected Factor(s)

* = p < 0.05 ** = p < 0.01 *** = p < 0.001 **** = p < 0.0001

Tukey test

at level 2 of flanker

comp	vs incomp	q =	3.09
comp	vs neut	q =	0.15
comp	vs mix	q =	0.22
incomp	vs neut	q =	3.24
incomp	vs mix	q =	2.87
neut	vs mix	q =	0.38

at level 4 of flanker

comp	vs incomp	q =	5.94	**
comp	vs neut	q =	1.34	
comp	vs mix	q =	2.10	
incomp	vs neut	q =	4.60	*
incomp	vs mix	q =	3.84	*
neut	vs mix	q =	0.76	

at level 6 of flanker

comp	vs incomp	q =	5.18	**
comp	vs neut	q =	1.02	
comp	vs mix	q =	1.08	
incomp	vs neut	q =	4.16	*
incomp	vs mix	q =	4.10	*
neut	vs mix	q =	0.07	

Tukeys for the differences between the compatibility conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of cond

comp	vs incomp	q =	8.20	***
comp	vs neut	q =	1.27	
comp	vs mix	q =	1.97	
incomp	vs neut	q =	6.93	***
incomp	vs mix	q =	6.24	***
neut	vs mix	q =	0.69	

Experiment5

Analysis of the RT data:

Analysis of Variance Summary Table

Data from exp5rt.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	26890.152	11	2444.559		
A (number)	29824.323	4	7456.081	62.730	0.0000 ****
(Error AxS)	5229.869	44	118.861		

Tukeys for the differences between the conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of number

Level 1	vs	Level 2	q =	Significance
0	vs	1	0.39	
0	vs	2	4.45	*
0	vs	3	10.35	***
0	vs	4	18.42	***
1	vs	2	4.84	*
1	vs	3	10.74	***
1	vs	4	18.82	***
2	vs	3	5.90	**
2	vs	4	13.98	***
3	vs	4	8.08	***

Analysis of the Error data:

Analysis of Variance Summary Table

Data from exp5err.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p	
Subjects	205.281	11	18.662			
A (number)	200.984	4	50.246	15.459	0.0000	****
(Error AxS)	143.012	44	3.250			

Tukeys for the differences between the conditions

Comparisons Between Means for Selected Factor(s)

* = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$ **** = $p < 0.0001$

Tukey test

Comparison between levels of number

0	vs 1	q =	1.18	
0	vs 2	q =	2.69	
0	vs 3	q =	6.34	***
0	vs 4	q =	9.54	***
1	vs 2	q =	1.51	
1	vs 3	q =	5.16	**
1	vs 4	q =	8.36	***
2	vs 3	q =	3.65	
2	vs 4	q =	6.85	***
3	vs 4	q =	3.20	

Experiment 6

Analysis of the RT data:

Analysis of Variance Summary Table

Data from exp6rt.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p	
Subjects	70008.959	11	6364.451			
A (number)	4496.637	4	1124.159	7.116	0.0002	***
(Error AxS)	6951.235	44	157.983			

Tukeys for the differences between conditions

Comparisons Between Means for Selected Factor(s)

* = p < 0.05 ** = p < 0.01 *** = p < 0.001 **** = p < 0.0001

Tukey test

Comparison between levels of number

4	vs 3	q =	3.16	
4	vs 2	q =	1.44	
4	vs 1	q =	4.61	*
4	vs 0	q =	6.83	***
3	vs 2	q =	1.72	
3	vs 1	q =	1.45	
3	vs 0	q =	3.67	
2	vs 1	q =	3.16	
2	vs 0	q =	5.38	**
1	vs 0	q =	2.22	

Analysis of the Error data:

Analysis of Variance Summary Table

Data from exp6err.txt

Within Subjects Design (alias Randomized Blocks)

Source of Variation	Sum of Squares	df	Mean Squares	F	p
Subjects	196.910	11	17.901		
A (number)	51.392	4	12.848	3.925	0.0082 **
(Error A x S)	144.028	44	3.273		

Tukeys for the differences between the conditions

Comparisons Between Means for Selected Factor(s)

* = p < 0.05 ** = p < 0.01 *** = p < 0.001 **** = p < 0.0001

Tukey test

Comparison between levels of number

4	vs 3	q =	1.13	
4	vs 2	q =	1.18	
4	vs 1	q =	3.05	
4	vs 0	q =	3.54	
3	vs 2	q =	2.31	
3	vs 1	q =	4.18	*
3	vs 0	q =	4.67	*
2	vs 1	q =	1.87	
2	vs 0	q =	2.36	
1	vs 0	q =	0.49	

EXPERIMENT 1 INSTRUCTIONS

INSTRUCTIONS

YOU WILL BE PRESENTED WITH A LINE OF SHAPES. EACH SHAPE WILL BE EITHER A CROSS, A SQUARE OR A TRIANGLE. THERE WILL BE EITHER 3, 5 OR 7 SHAPES. THE MIDDLE SHAPE WILL ALWAYS BE A CROSS OR A SQUARE AND NEVER A TRIANGLE.



WHAT YOU HAVE TO DO IS TO IGNORE THE OUTER SHAPES AND RESPOND ONLY TO THE MIDDLE SHAPE. IF THE MIDDLE SHAPE IS A SQUARE, THEN PRESS THE 'M' KEY. IF THE MIDDLE SHAPE IS A CROSS, THEN PRESS THE 'C' KEY. KEEP YOUR FINGERS OVER THESE KEYS THROUGHOUT THE EXPERIMENT. YOUR REACTION TIMES WILL BE RECORDED SO PLEASE TRY TO RESPOND AS QUICKLY AS POSSIBLE WHILST ALSO BEING ACCURATE.

BEFORE EACH TRIAL BEGINS, A CIRCLE WILL APPEAR IN THE MIDDLE OF THE SCREEN WHICH INDICATES WHERE THE MIDDLE SHAPE WILL APPEAR. FOCUS ON THIS CIRCLE AS THIS WILL HELP YOU TO IGNORE THE OUTER SHAPES. THE SHAPES WILL REPLACE THIS CIRCLE ONE SECOND LATER SO KEEP WATCHING.

THERE ARE 3 BLOCKS OF EXPERIMENTAL TRIALS. IN ONE BLOCK THERE WILL BE 3 SHAPES AND IN THE OTHER BLOCKS THERE WILL BE 5 AND 7 SHAPES. BEFORE EACH EXPERIMENT BLOCK YOU WILL BE GIVEN A PRACTICE BLOCK THAT HAVE THE SAME NUMBER OF SHAPES.

PRESS THE SPACE BAR TO START THE FIRST PRACTICE BLOCK.

EXPERIMENT 2 INSTRUCTIONS

YOU WILL BE PRESENTED WITH A LINE OF SHAPES. EACH SHAPE WILL BE EITHER A CROSS, A SQUARE OR A TRIANGLE. THERE WILL BE EITHER 3, 5 OR 7 SHAPES. THE MIDDLE SHAPE WILL ALWAYS BE A CROSS OR A SQUARE AND NEVER A TRIANGLE.



WHAT YOU HAVE TO DO IS TO IGNORE THE OUTER SHAPES AND RESPOND ONLY TO THE MIDDLE SHAPE. IF THE MIDDLE SHAPE IS A SQUARE, THEN PRESS THE 'M' KEY. IF THE MIDDLE SHAPE IS A CROSS, THEN PRESS THE 'C' KEY. KEEP YOUR FINGERS OVER THESE KEYS THROUGHOUT THE EXPERIMENT. YOUR REACTION TIMES WILL BE RECORDED SO PLEASE TRY TO RESPOND AS QUICKLY AS POSSIBLE WHILST ALSO BEING ACCURATE.

BEFORE EACH TRIAL BEGINS, A CIRCLE WILL APPEAR IN THE MIDDLE OF THE SCREEN WHICH INDICATES WHERE THE MIDDLE SHAPE WILL APPEAR. FOCUS ON THIS CIRCLE AS THIS WILL HELP YOU TO IGNORE THE OUTER SHAPES. THE SHAPES WILL REPLACE THIS CIRCLE ONE SECOND LATER SO KEEP WATCHING.

THERE ARE 3 BLOCKS OF EXPERIMENTAL TRIALS. IN ONE BLOCK THERE WILL BE 3 SHAPES AND IN THE OTHER BLOCKS THERE WILL BE 5 AND 7 SHAPES. FOR EACH BLOCK THERE ARE 2 PRACTICE BLOCKS OF TRIALS FOLLOWED BY 4 EXPERIMENTAL BLOCKS OF TRIALS.

PRESS THE SPACE BAR TO START THE FIRST PRACTICE BLOCK.

EXPERIMENTS 3 AND 4 INSTRUCTIONS

INSTRUCTIONS

YOU WILL BE PRESENTED WITH A LINE OF SHAPES. THERE WILL BE EITHER 3,5 OR 7 SHAPES. EACH OF THE SHAPES WILL BE EITHER A RIGHT OR LEFT POINTING ARROW OR A CIRCLE. THE MIDDLE SHAPE WILL BE EITHER A RIGHT OR LEFT POINTING ARROW AND NEVER A CIRCLE



WHAT YOU HAVE TO DO IS TO IGNORE THE OUTER SHAPES AND RESPOND ONLY TO THE MIDDLE SHAPE. IF THE MIDDLE SHAPE IS A RIGHT POINTING ARROW, THEN PRESS THE 'M' KEY. IF THE MIDDLE SHAPE IS A LEFT POINTING ARROW, THEN PRESS THE 'C' KEY. KEEP YOUR FINGERS OVER THESE KEYS THROUGHOUT THE EXPERIMENT.

YOUR REACTION TIMES WILL BE RECORDED SO PLEASE TRY TO RESPOND AS QUICKY AS POSSIBLE WHILST ALSO BEING ACCURATE. BEFORE EACH TRIAL BEGINS A SMALL CROSS WILL APPEAR IN THE MIDDLE OF THE SCREEN WHICH INDICATES WHERE THE MIDDLE SHAPE WILL APPEAR. FOCUS ON THIS CROSS AS THIS WILL HELP YOU TO IGNORE THE OUTER SHAPES. ONE SECOND LATER THE SHAPE WILL REPLACE THIS CROSS SO KEEP WATCHING.

THERE ARE 3 BLOCKS IN THIS EXPERIMENT THAT ARE DEFINED BY THE NUMBER OF SHAPES. IN ONE BLOCK THERE ARE 3 SHAPES AND IN THE OTHER BLOCKS THERE ARE 5 AND 7 SHAPES. FOR EACH BLOCK THERE ARE 2 PRACTICE BLOCKS OF TRIALS FOLLOWED BY 4 EXPERIMENTAL BLOCKS OF TRIALS

PRESS THE SPACE BAR TO BEGIN THE FIRST PRACTICE BLOCK

EXPERIMENT 5 INSTRUCTIONS

INSTRUCTIONS

YOU WILL BE PRESENTED WITH A LINE OF 5 ARROWS. THE ARROWS WILL BE EITHER POINTING LEFT OR POINTING RIGHT. WHAT YOU HAVE TO DO IS TO RESPOND ONLY TO THE MIDDLE ARROW WHILST IGNORING THE OUTER ARROWS.



IF THE MIDDLE ARROW IS POINTING RIGHT, THEN PRESS THE 'M' KEY. IF THE MIDDLE ARROW IS POINTING LEFT, THEN PRESS THE 'C' KEY. KEEP YOUR FINGERS OVER THESE KEYS THROUGHOUT THE EXPERIMENT.

YOUR REACTION TIMES WILL BE RECORDED SO PLEASE TRY TO RESPOND AS QUICKLY AS POSSIBLE WHILST ALSO BEING ACCURATE.

BEFORE EACH TRIAL BEGINS A CROSS WILL APPEAR IN THE MIDDLE OF THE SCREEN WHICH INDICATES WHERE THE MIDDLE ARROW WILL APPEAR. STARE AT THIS CROSS AS THIS WILL HELP YOU TO IGNORE THE OUTER ARROWS. THE CROSS WILL BE REPLACED ONE SECOND LATER WITH THE ARROWS SO KEEP WATCHING

THERE ARE TWO PRACTICE BLOCKS OF TRIALS FOLLOWED BY FOUR EXPERIMENTAL BLOCKS OF TRIALS

PRESS THE SPACE BAR TO BEGIN THE FIRST PRACTICE BLOCK OF TRIALS.

EXPERIMENT 6 INSTRUCTIONS

INSTRUCTIONS

YOU WILL BE PRESENTED WITH 3 SHAPES IN A LINE. THE SHAPES WILL BE EITHER SQUARES OR CIRCLES AND WILL BE EITHER RED OR GREEN. THE MIDDLE SHAPE WILL ALWAYS BE EITHER A GREEN SQUARE OR A RED CIRCLE AND NEVER THE OTHER COMBINATIONS.



WHAT YOU HAVE TO DO IS TO IGNORE THE OUTER TWO SHAPES AND RESPOND ONLY TO THE MIDDLE SHAPE. IF THE MIDDLE SHAPE IS A GREEN SQUARE, THEN PRESS THE 'M' KEY. IF THE MIDDLE SHAPE IS A RED CIRCLE, THEN PRESS THE 'C' KEY. PLEASE KEEP YOUR FINGERS OVER THESE KEYS THROUGHOUT THE EXPERIMENT.

YOUR REACTIONS TIMES WILL BE RECORDED SO PLEASE RESPOND AS QUICKLY AS POSSIBLE WHILST ALSO BEING ACCURATE.

BEFORE EACH TRIALS BEGINS, A CROSS WILL APPEAR IN THE CENTER OF THE SCREEN WHICH INDICATES WHERE THE MIDDLE SHAPE WILL APPEAR. FOCUS IN THIS CROSS AS THIS WILL HELP YOU TO IGNORE THE OUTER SHAPES. ONE SECOND LATER THE CROSS WILL BE REPLACED BY THE SHAPES SO KEEP WATCHING

YOU WILL BE GIVEN TWO PRACTICE BLOCKS OF TRIALS FOLLOWED BY FOUR EXPERIMENTAL BLOCKS OF TRIALS.
PRESS THE SPACE BAR TO BEGIN THE FIRST PRACTICE BLOCK