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The relationship between inhibitory control and System 1 and System 2 processes in deductive and spatial reasoning.

A thesis submitted in partial fulfilment of the requirements for the Degree of

Master of Arts in Psychology

at the University of Canterbury

by

Charlotte Graham

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Abstract

Dual Processing theory proposes that the ability to over ride associative (System 1) in favour of analytical (System 2) processed in deductive reasoning may depend on inhibitory control. The present study applies this association to a spatial reasoning task by adapting a mental rotation task to a multichoice format including System 1 (mirror) and System 2 (rotated image) responses. Fifty undergraduate volunteers from the University of Canterbury responded to a Stroop task as a measure of inhibitory control that was compared with System 1 and System 2 responding from a spatial and a deductive reasoning task. It was expected that people with weaker inhibitory potential would make more System 1 and fewer System 2 responses in both deductive and visual-spatial reasoning tasks. Contrary to expectation System 2 responding dominated for both tasks and correlations between both reasoning tasks and measures of inhibitory control were non-significant. The differing idiosyncratic demands of each task may have obscured any common variables associated with inhibitory control. This research initiated a test for the presence of System 1 and System 2 in spatial reasoning.

1.0 Introduction

1.1 System 1 and System 2 (Evans 2001, 2003)

Contemporary reasoning research distinguishes two systems of reasoning (Evans 2002). System 1 reasoning is an implicit process of reasoning which is rapid, automatic, and independent of general intelligence (Evans, 2003). System 1 reasoning is also known as associative reasoning because it relies on quick associations to identify objects and events with prior knowledge. System 1 reasoning provides people with heuristics to solve everyday problems. When a learned response has been practised until it is automatic, it becomes part of System 1 reasoning. System 1 thinking is said to be unconscious, so people become conscious only of the final product of System 1 thinking processes. System 1 reasoning is said to occur when people identify a situation and generate a rapid, well practised solution, such as when people step on the brake pedal at a red traffic light. In contrast, System 2 reasoning is said to be slow, explicit, and controllable, it is correlated with general intelligence and often requires more effort. System 2 reasoning is thought to be required for analytical mathematical types of reasoning, and is often referred to as analytical reasoning. System 2 should be useful in novel situations where people have to generate more difficult solutions in response to an event. People tend to have more conscious awareness of System 2 thinking processes. System 2 processing might be required when making plans or solving logic problems. Although reasoning research distinguishes System 1 and System 2 modes of thinking, very little research has applied these models to spatial reasoning. The present thesis proposes extending the distinction to spatial reasoning by using a variant of the mental rotation paradigm. This thesis also explores the role of individual differences in inhibitory control in the propensity to favour System 1 over System 2 models in deductive and spatial reasoning.

1.2 Belief Bias (Evans, 2001)

Previous studies on deductive reasoning have demonstrated that associative reasoning processes (System 1) can dominate analytical processing (System 2) (Evans, 2001; Stanovich and West, 2002). Deductive reasoning tasks usually involve assessing the validity of a conclusion from two or more given premises, by deducing the logical validity of the given form of the argument, while ignoring content and inferences based on prior belief or knowledge. Reasoning problems can be classified according to the relation between logical validity and prior belief or knowledge. Logic-belief consistent problems are those where conclusions derived from logic calculus are consistent with prior knowledge or belief. Logic-belief conflict problems are those where conclusions derived from logic calculus contradict prior belief or knowledge. Neutral problems are devoid of semantic content and are those where the premises and conclusions do not involve prior belief or knowledge. People tend to produce choices that agree with prescriptions from logic calculus on deductive reasoning tasks when the truth-value of the content (either true or false) is consistent with the logical form of the argument (Evans, 2003). When the truth-value in the content is at odds with the logical conclusion belief bias may occur. Belief bias is the tendency to solve logic-belief inconsistent problems using the truth-value of the content rather than logical validity.

Dual process theory is used to account for the belief bias effect in deductive reasoning tasks. When the logic response that relies on System 2 and the prior belief response that relies on System 1 are put into conflict, people tend to respond according to prior belief (Stanovich, 1999; Evans 2003). Dual processing theory argues that System 1 responding is so powerful that even when intelligent adults, such as university students are specifically instructed to respond according to the logical validity of the argument, they still show a tendency to respond according to prior belief. Dual process theory argues that System 1 responding is so powerful that it is difficult to suppress, in favour of a System 2 response, and therefore in deductive reasoning tasks, people display a tendency to respond according to prior belief, rather than on the logical validity of the argument.

1.3 Inhibition (Nigg, 2001)

The ability to suppress a System 1 response in favour of a System 2 response is considered to be related to individual differences in inhibition (Handley et al, 2004). In this context inhibition is taken to be the deliberate suppression of a prepotent cognition or response in order to achieve an internally represented goal (Nigg, 2001). This class of inhibition is referred to as “executive inhibition”, although Nigg distinguishes several types (Friedman and Miyake, 2004). As children develop, inhibition ability tends to improve and the active suppression mechanism becomes more efficient. Children become more efficient at keeping task irrelevant information from entering the stream of processing and are better able to deactivate information which is peripheral to central task performance (Harnishfeger and Bjorklund, 1994). Variations in inhibition are thought to directly affect behavioural impulsivity, self-control and selective attention as well as reasoning performance. Friedmann and Miyake (2004) and others have used the Stroop task to assess prepotent response inhibition because it measures the ability to override the habitual more automated response of reading in favour of colour naming. In the present study the Stroop task is used to determine whether people who have weaker inhibitory control will provide more System 1 responses in both visual-spatial and deductive reasoning tasks compared to those who have stronger response inhibition scores.

To demonstrate whether there is a correlation between inhibition and the tendency for System 1 to dominate System 2 processing in both types of reasoning, this study will compare measures of inhibitory control using the Stroop task with the frequency of System 1 errors in both deductive and visual spatial reasoning tasks. There are clearly demonstrated neural subsystems implicated in the suppression of the preponent colour name in the Stroop task. In particular the anterior cingulate gyrus, which is known to be involved in suppression and executive control, is activated during incongruent ink colour- colour word Stroop trials (Nigg, 2001). The Stroop task can be considered to measure the ability to inhibit irrelevant stimuli when the speed of naming the colour of rows of “x’s”, with the speed of naming the ink colour of incongruent colour words is compared. By comparing the Stroop inhibition scores to measures of System 1 responding in deductive and visual-spatial reasoning it will be possible to determine whether those exhibiting greater inhibitory control display a tendency to suppress System 1 responses in favour of System 2 responses.

1.4 Mental Rotation (Shepard and Metzler, 1971)

Although reasoning research distinguishes System 1 and System 2 processing, there has been very little application of these models to spatial reasoning. This thesis aims to further advance the reasoning distinction in dual processing theory by using a variant of the mental rotation paradigm. An adaptation of Shepard and Metzler's (1971) mental rotation work will be used to provide possibilities for both System 1 and System 2 responses. This is achieved in a multi-choice version of the Shepard and Metzler mental rotation task in which participants select a shape that is identical to a designated standard shape (see Appendix B). The System 2 response requires rotation of one of the comparison set into alignment with the standard in order to determine their identity. The System 1 alternative is a mirror image representation of the standard and requires no rotation to bring it into alignment with the standard. By adapting the mental rotation task to induce competing System 1 and System 2 processing, it may be possible to determine whether System 1 processing has a tendency to dominate System 2 in the visual-spatial domain as well as deductive reasoning situations.

It will also be interesting to compare responses from the deductive and mental rotation tasks with a measure of inhibitory performance, to determine whether the relationship between inhibitory control and the ability to suppress System 1 responses is similar for spatial reasoning and deductive reasoning tasks. A correlation between measures of inhibitory control and the tendency to make System 1 errors has been reported in several studies involving various deductive reasoning tasks (Handley, et al., 2004) and could reflect differences in the ability to decontextualise a problem from prior knowledge or difficulties in performing in an unfamiliar environment (Stanovich and West, 2002).

The present study investigates how individual differences in inhibitory control might affect visual-spatial and deductive reasoning. Given the previous findings, it is expected that measures of inhibitory control, deductive reasoning and visual spatial reasoning should be positively correlated. This study could demonstrate that there is a tendency to provide System 1 responses in both visual-spatial and deductive reasoning tasks, and that this tendency is mediated by individual differences in inhibitory control, which may be involved in the suppression of System 1 responding in favour to System 2 processes for both types of reasoning.

2.0 Behavioural Studies

2.1 Deductive Reasoning and Inhibitory Control

(Handley et al., 2004)

It could be suggested that individual differences in executive inhibitory control reflect variations in general cognitive ability. Under this assumption a correlation between deductive reasoning scores and Stroop interference would demonstrate that more able people solve harder problems better. That possibility is excluded by findings from Handley et al. (2004) which demonstrate that inhibitory control can be distinguished from general cognitive ability, working memory, or intelligence. Handley et al. (2004) provided 61, ten year old children with conditional and relational, deductive reasoning items in which the believability of the conclusion and its logical validity were systematically manipulated. The items were either logically valid or invalid and either neutral, believable or unbelievable. Participant responses which favoured the belief status of the conclusion required a tendency to disregard the logical validity of the task and demonstrated a tendency toward System 1 responding. Responses which favoured logical validity and ignored the belief status of the conclusion demonstrated analytical reasoning and System 2 involvement.

Participant responses to the deductive reasoning items were compared with measures of inhibitory control. Inhibitory control was measured using a stop signal task. Participants responded with a key press when an “x” or an “o” was presented on a computer screen, but had to inhibit a response on random trials whenever a tone preceded an “x” or an “o”. Inhibitory control was measured by the number of correctly “stopped” responses during the stop signal trials. Handley et al. found that participants who responded according to the belief status in the deductive reasoning task received lower scores on the stop signal task, and those who tended to respond according to the logical validity received higher scores on the inhibition task. Handley et al. argued that participants with lower inhibition scores also received lower scores on the deductive reasoning task because they had difficulty suppressing the System 1 response in favour of the System 2 response. The Handley et al. study demonstrated support for the relationship between inhibitory control (measured as the ability to suppress a prepotent response) and the ability to suppress a System 1 response to allow for the processing of a System 2 response in a deductive reasoning task.

Prior knowledge intrudes over analytic processes in belief bias deduction problems. There is no comparable prior knowledge regarding 3-D blocks of the Shepard type that leads participants to favour mirror image over rotated versions. This is spatial/perceptual reasoning, so the capture of System 1 comes from what the mirror image looks like compared to the standard. System 1 tends to rely on associations, stereotypes, similarity and visual recognition, as well as prior belief (Sloman, 1996). The mirror image is used in the mental rotation task as a System 1 response because the tendency to accept a "sloppy" match has to be resisted in favour of an analytic rotation. This System 1 response could be a distracting irrelevant intrusion, which may require inhibition to suppress.

2.2 Dual-Code Theory (Santa, 1977)

Imagery based on knowledge from stored representations in working memory is involved in both mental rotation and deductive reasoning. This process may be involved in mental rotation when forming a comparison between a standard and rotated object, and during deductive reasoning to compare relations between the premises and conclusion. Dual-code theory (Pavio, 1971) claims that separate representations are required for verbal and spatial information (Anderson, 2005). This suggests the importance of comparing the effects of inhibition on System 1 and System 2 reasoning for both verbal and spatial information. Santa's (1977) findings demonstrate support for Dual code theory. Santa compared a geometric experimental condition during which participants studied an array of three geometric objects, with a verbal experimental condition, where participants studied words arranged exactly as the objects in the geometric condition were arranged (Fig 2.1). All the test stimuli in the geometric condition involved geometric objects and in the verbal condition all test stimuli involved words, but otherwise the test stimuli in both conditions presented the same possibilities. The participants' task was to verify that the test array contained the same elements as the study array, although not necessarily in the same spatial configuration. The first test array was identical to the study array (same configuration condition). In the second array, the elements were displayed in a line (linear configuration condition). Santa (1977) found that in the geometric condition participants' were accurate and faster in their judgements when the geometric test array preserved the configuration condition information in the study array. But when participants had encoded words from the study array linearly, they were faster when the test array was linear. According to Anderson (2005), some visual information such as geometric objects tend to be stored according to spatial position, while other information such as words tend to be stored according to linear order (or normal reading order right to left). If Dual-code theory claims that there are separate processes for storing images based on words and spatial configurations, then it would be worth comparing the effects of inhibitory control on System 1 and System 2 reasoning for both types of imagery storage processes.

Figure 2.1

Santa's 1977 Linear and Configuration Visual Information Storage Experiment

{ SHAPE * MERGEFORMAT **}**

2.3 Visual-Spatial Reasoning (Tversky, 2005)

When reasoning tasks are presented in either a picture or verbal format there are qualitative differences in the cognitive processing involved. For example, Tversky (1969) found in a same-different memory study, that when participants expected the target stimulus to be a picture they encoded the first stimulus pictorially. When participants expected the target stimulus to be a name they encoded it verbally, irrespective of how the first stimulus was presented. The cognitive processing involved in mental rotation has been linked to perceptual processing, while the processing involved in reading and listening involves constructing representations which are more schematic and less detailed (Tversky, 2005). Tversky's research found qualitatively different cognitive processing involved in pictorially and verbally presented stimuli. It will therefore, be interesting to compare the different presentation formats of visual-spatial and deductive reasoning to discover whether the tendency for System 1 to dominate System 2 holds for both types of cognitive processing.

Tversky asserts that even though there are qualitative differences between pictorial and verbal representations, reasoning about these representations may involve similar visual-spatial processes. This suggests that the effect of inhibition on System 1 and System 2 processing could apply to reasoning based on both visual and verbal representations. According to Tversky (2005), reasoning means going beyond the information given or to transform the information in some way. Visual-spatial thinking is, therefore, involved in all types of reasoning. This is because whether a person is reasoning according to rules as in deciding whether a conclusion follows logically from its premises, or with visual spatial information (as in deciding whether a rotated shape is identical to a designated standard shape) they are required to transform or manipulate both types of information in a similar manner. Therefore, even though verbal and visual information are represented in different formats, reasoning about both types of information can involve visual-spatial thinking. This suggestion could then provide support for the idea that if System 1 and System 2 processing occurs in reasoning based on verbal representations then similarly there may be System 1 and System 2 parallels where thinking involves visuo-spatial representations.

3.0 Neuroimaging Evidence

3.1 A Relationship Between Reasoning and Inhibition (Goel and Dolan, 2003)

Goel and Dolan (2003) used event related fMRI to study the functional neuroanatomy associated with belief bias during neutral, logic-belief consistent (facilitory) and logic-belief conflict (inhibitory) deductive reasoning conditions. Goel and Dolan's findings provide neurological evidence for dual processing theory and they describe how the brain mechanisms interact when System 1 is inhibited to allow System 2 processing during deductive reasoning. Goel and Dolan (2003) gave participants several reasoning tasks where the belief value and logical validity of the conclusion were systematically manipulated so that with logic-belief conflict trials answers based on prior belief would be inconsistent with the logical validity, while in logic-belief consistent trials the belief value and logical validity were consistent. Participants were asked to press a button to indicate whether they thought the conclusion was logically valid or not.

An fMRI analysis comparing blood oxygenation level dependent activation (BOLD) revealed a left temporal lobe system involvement when reasoning was based on prior belief, and involvement of a bilateral parietal system when logically based reasoning occurred. An event related fMRI scanning during correct belief-neutral trials showed activation of the bilateral superior parietal lobes. The parietal system is known to be involved in the internal representation and manipulation of spatial information and abstract mathematical reasoning involving numerical quantities. This suggests that the neural structures involved in spatial processing are the basic building blocks for belief-neutral logical reasoning (Goel and Dolan, 2003). An analysis of BOLD activation during incorrect logic-belief conflict trials, when participants answered according to prior belief instead of logic, revealed that the left ventromedial prefrontal cortex (VMPFC) was activated. The neural structures of the ventromedial prefrontal cortex have been implicated in guessing, intuitive responding, and in non-logical belief based responding (Goel and Dolan, 2003). Further analysis revealed relative deactivation of the left VMPFC during logic-belief consistent trials and correct logic-belief conflict trials. The patterns of activation observed by Goel and Dolan provide evidence favouring a distinction between semantic belief laden components of reasoning and logico-deductive components that appear to some degree at least to be fundamentally spatial in origin.

Goel and Dolan (2003) also illustrated the brain processing involved in the inhibition of a System 1 response in favour of System 2 responses during deductive reasoning tasks. For a correct response during logic-belief conflict trials participants were required to recognise the conflict between the believability and logical validity of the conclusion, inhibit a response consistent with their belief, and engage a reasoning mechanism. For an incorrect response participants were unable to detect the conflict between belief and logic, or unable to inhibit the response based on prior belief. Goel and Dolan point out that the right prefrontal cortex has been previously implicated in inhibitory control. because it has been found to be activated when participants successfully inhibited a response associated with belief bias and provided the correct logical response. These findings, therefore, implicate the role of inhibitory control in the suppression of a System 1 in favour of System 2 responding.

4.0 Theoretical Support for the Current Study

4.1 Mental Models Theory (Johnson-Laird, 2005)

While dual processing theory focuses on providing explanations for belief bias in deductive reasoning tasks, mental models theory also provides an account of visual-spatial reasoning as well as providing an alternative explanation for belief bias in deductive reasoning. According to Johnson-Laird (2005) perception provides people with models of the world that lie outside of themselves, while an understanding of discourse provides people with models of the world that a speaker describes to them. Thinking which enables people to anticipate the world, and to choose a course of action, relies on internal manipulations of these mental models. Mental model theory suggests that in deductive reasoning, people form mental models of the propositions and competing mental models that represent the alternative logical form of the argument. Therefore, even though reasoning problems may be presented either spatially (as in mental rotation) or verbally (as in deductive reasoning), mental model theory supposes that the same reasoning processes are elicited by both types of reasoning problems (Goel, Buchel, Frith, and Dolan, 2000).

While dual processing theory can explain the way in which System 1 and System 2 processes interact to affect belief bias in deductive reasoning, the mental model account can provide an explanation for both visual spatial and deductive reasoning. From the studies discussed so far representing the dual processing approach, it is concluded that there is neurological evidence for two distinct brain mechanisms corresponding to System 1 and System 2 in deductive reasoning. Furthermore, these findings suggest that inhibitory processes may affect the ability to override System 1 processing in favour of System 2. With the addition of evidence from the studies representing the mental models approach, it is also possible to conclude that reasoning about verbal and visual stimuli may involve overlapping neurological systems. By combining evidence from both System 1 versus System 2 and Mental Model approaches it is possible to infer that System 1 and System 2 processes could apply to reasoning about both visual and verbal stimuli.

Therefore based on findings from the previous studies, the present study aims to extend the finding that System 1 responding, which produces errors in deductive reasoning, also results in errors in visual-spatial reasoning and to show that people who have weaker inhibition control would provide more System 1 responses in both visual-spatial and deductive reasoning tasks compared with those who have stronger response inhibition scores.

5.0 Measuring Inhibition and Reasoning

The study by Handley et al. (2004) provided evidence of System 1 and System 2 reasoning by providing an accurate measure of deductive reasoning from a set of relational and conditional reasoning problems. In the present study deductive reasoning was measured from a set of questions involving relational and conditional reasoning problems derived from Handley et al. 2004. The conclusions were either consistent, neutral, or inconsistent with respect to prior belief, and either logically valid, logically invalid, or indeterminate and required a yes/no response (see appendix A). For deductive reasoning a measure of System 2 processing was derived from responses that were consistent with the logical validity of each conclusion while a measure of System 1 processing was derived from responses that were consistent with the believability of each conclusion regardless logical validity. The mental rotation test was adapted from Shepard and Metzler, 1971. Each trial comprised a standard block and four comparison blocks. The four comparison blocks included the rotated standard block (System 2), a mirror reflection of the standard block (System 1) and two distractor blocks that were neither mirror images nor rotations of the standard.

5.1 Hypothesis

Three hypotheses were tested in the present study. Firstly in deductive reasoning people will tend to opt for the dominant heuristic (System 1) response rather than rely on the slower more effortful processing required to make an analytical (System 2) response and it is expected that System 1 responses will be made more quickly. Second, people will also make System 1 responses in visual spatial reasoning tasks where it is expected that incorrect mirror image choices will be made more often and more quickly than correct rotated versions of the standard. Finally people with weaker inhibitory potential will make more System 1 (associative errors) and fewer System 2 (analytical) responses in both deductive and visual-spatial reasoning tasks.

6.0 Method

6.1 Participants

Fifty undergraduate volunteers from the University of Canterbury, were recruited via email. There were 22 Males and 28 Females. Participants received $7 student cafeteria vouchers for participation in the study.

6.2 Deductive Reasoning Task

The deductive reasoning task consisted of 12 relational and 12 conditional reasoning problems adapted from Handley et al. (2004) for use with local university students. Each problem consisted of three sentences, including two premises and a conclusion, which appeared simultaneously on the screen and remained present until a "Yes" or "No" response was made indicating the validity of the conclusion. The conclusions to reasoning problems were varied to be either, believable, unbelievable or neutral and either logically valid, invalid or indeterminate. (Table 6.1, and Appendix A).

Table 6.1

The Number of Reasoning Problems in Each Category Based on Belief and Logical Validity Used in the Deductive Reasoning Task

Belief	Validity	Example	No. of problems in each category
Believable	Valid	Whales are bigger than dolphins. Dolphins are bigger than goldfish. *So, are whales bigger than goldfish?*	2
Believable	Invalid	Dunedin is North of Christchurch. Christchurch is North of Wellington. *So, is Wellington North of Dunedin?*	5
Unbelievable	Valid	Cricket balls are bigger than golf balls. Golf balls are bigger than rugby balls. *So, are cricket balls bigger than rugby balls?*	5
Unbelievable	Invalid	Goldfish are smaller than dolphins. Dolphins are smaller than whales. *So, are whales smaller than goldfish?*	2
Neutral	Valid	Nids are bigger than Yigs. Yigs are bigger than gons. *So, are Nids bigger than gons?*	1
Neutral	Invalid	Dambles are stronger than Heagles. Heagles are stronger than Ringoes. *So, are Ringoes stronger than Dambles?*	1
Neutral	Indeterminate	Bappeds are happier than Zingles. Wabs are happier than Zingles. *So, are Bappeds happier than Wabs?*	3
Believable	Indeterminate	Sunflowers are grown in fields. Things that contain chemicals are grown in fields. *So, do sunflowers contain chemicals?*	2
Unbelievable	Indeterminate	Bees fly in the sky. Insects that live on mars fly in the sky. *Do bees live on mars?*	2

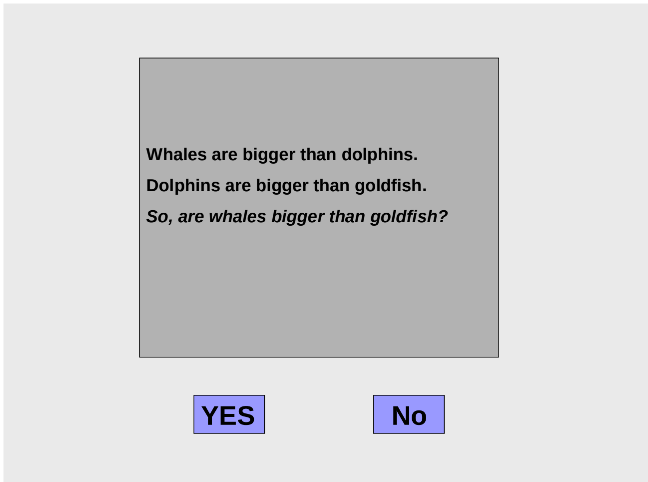
Statements were arranged so that incongruent (prior belief was inconsistent with the logical validity of the conclusion) and congruent (prior belief was consistent with the logical validity of the conclusion) statements each included an equal number of correct “yes” and “no” responses (based on the logical validity of the conclusion). Problems that were logically indeterminate were treated as distracters and not included in the analysis of the results. Participants were instructed to decide for each problem whether the conclusion was correct, assuming that the first two statements were true. The following instruction screen was read before commencing trials:

> “Reasoning Problems: In this task you are going to receive twenty five problems, each with two statements and one conclusion. It is important to pretend that the first two statements in each problem are true (even if they sound a bit funny or strange). For each problem, your task is to decide whether the conclusion (in italics) would be correct or not, assuming that the first two statements are true. Does the conclusion follow from the two statements (yes/no)”.

After the instructions the deductive reasoning background was presented (Figure 6.1) (168 mm high and 226mm wide) and remained in view throughout the deductive reasoning task. The background consisted of three rectangles including a large central rectangle (96mm high and 116mm wide) and two text boxes (each 12mm high and 23mm wide) set 34mm apart. Each deductive reasoning problem was presented in the large rectangle, the word “Yes” was written in the centre of the box on the left and the word “No” in the box on the right. Participants indicated their response by using the mouse to locate the cursor and click in the “Yes” or “No” box. Reasoning stimuli were presented on a 17 inch Viewsonic computer screen using Superlab Pro 2.0 to control presentation, and to record response times and response choices.

Figure 6.1

Example of the On Screen Display Used for the Deductive Reasoning Task

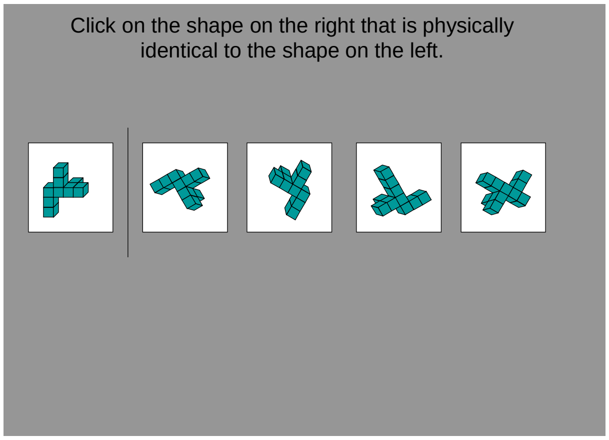


6.3 Mental Rotation Task

The mental rotation task comprised one practice and 17 test displays. Each display contained five boxes (27mm high and 25mm wide) (Figure 6.2) each containing a 2-D depiction of a 3-D block object. A standard object appeared in the left most box. The remaining four boxes contained a picture plane rotation of the standard object (30 to 330 degrees in 30 degree increments), an aligned mirror image version of the standard object and two foil objects that were neither mirror image or rotated versions of the standard. The positions of the comparison blocks in each display were randomly determined. Block objects were formed from 7 to 15 three dimensional blocks (3mm high, 3mm long and 2mm wide). The standard and comparison objects in any display contained the same number of component blocks. Participants were instructed to use the mouse to position the cursor and “Click on the shape on the right that is physically identical to the shape on the left.” This instruction remained in view at the top of every display screen and an arrow with accompanying text identified the correct rotated image on the instruction display. Displays remained in view until a response was made whereupon the next display appeared without delay. Superlab Pro 2.0 was used to control the trial sequence and record response choices and response times.

Figure 6.2

Example of the On Screen Display Used for the Mental Rotation Task



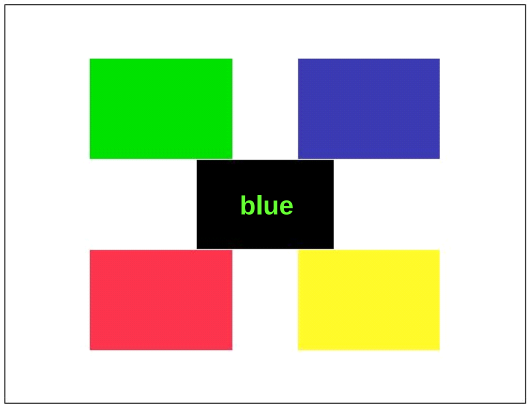
6.4 Stroop Task

The difference in ink colour identification times for incongruent colour names and control stimuli in a Stroop task provided the measure of inhibitory control (Nigg, 2001). According to Nigg, reading is a faster and more automatic process than colour naming and people with poorer inhibition have greater difficulty inhibiting the irrelevant reading response in preference to colour naming. The Stroop task can therefore, be considered as a measure of the effectiveness of an interference suppression mechanism involved in inhibition.

The display (see Figure 6.3) comprised a central black rectangle measuring 28mm high by 45mm wide upon which the incongruent colour names and control strings of *X's* appeared. This was surrounded by four rectangular coloured patches each measuring 32mm high and 47mm wide. Participants indicated the font colour of the text when it appeared in the central black rectangle by moving the cursor from the centre of the central black rectangle to the appropriate coloured area and clicking the left mouse button. On each trial centred in the central black rectangle were either a row of X's (printed in blue, green, red, or yellow) or a colour word written in one of three incongruent colours. Time between the onset of a word or letter string in the central rectangle and click of the mouse in one of the four coloured rectangles was measured together with identification of the area clicked. The stimuli were presented using locally produced software, which was used to control screen presentation, record participant selection and response times. This software was used because it was capable of recording response times to millisecond accuracy which is not guaranteed in Superlab with cursor positioning input.

Figure 6.3

Example of the On Screen Display Used for the Stroop Task.



Participants completed 432 Stroop trials. The four colours generated a set of 4 x 3 = 12 incongruent colour word stimuli. Rows of *X*'s equal in length to the colour names (3, 4, 5 and 6 letters) were constructed and each printed in the four colours to give a set of 4 x 4 = 16 neutral stimuli. To give a total of 72 trials for each block, there were 36 incongruent and 36 neutral stimuli. Each block comprised 3 sets of the 12 incongruent colour word stimuli (3 x 12 = 36), 2 sets of the 16 neutral stimuli (2 x 16 = 32), and an extra set of 4 rows of *X*'s each a different length and printed in a different ink colour. These stimuli were randomised within each of six blocks to yield a total of 432 trials which were presented in a continuous sequence.

The first screen instructed participants that they would be required to click the mouse icon on a colour patch that matched the ink colour of the letters in the centre, and to do so as fast and as accurately as possible. The instruction screen included a small example (similar to the one in Figure 6.3) Participants were told that there were 432 presentation screens and that the task would take about ten minutes. Participants were asked if they understood the procedure and then told to press the space bar to begin the first trial. This was followed by the appearance of the background screen and first letter presentation. The background screen comprising the central black rectangle and the four surrounding coloured rectangles remained in view during all

Stroop trials. Only the text appearing in the central black region changed, and it did so immediately the mouse was clicked in one of the four coloured rectangles.

6.5 Procedure

Participants were tested individually in a quiet room. They first read an information sheet and signed a consent form. They then completed the Stroop task and either the deduction or spatial reasoning task, the order of these tasks being randomly determined The complete experiment took between 20-30 mins depending on the speed of the participant. At the end of the experiment each participant was thanked, given a $7.00 café voucher and a brief explanation of the research.

7.0 Results

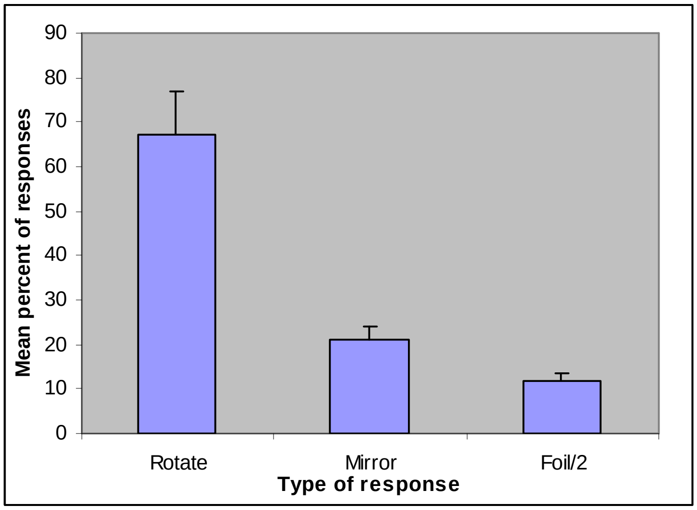
7.1 Deductive Reasoning Results

A dominance of System 1 over System 2 responding was hypothesised. System 1 responding can be detected on conflict problems where belief is pitted against validity. The proportion of the 10 conflict (believable invalid + unbelievable valid) problems that receive a belief consistent response provides a measure of System 1 dominance. Participants who always chose the logically valid response would score zero by this measure. A participant who chose at random observing neither validity or belief would on average score 50%. Over the 50 participants the proportion of conflict trials given belief consistent responses ranged from 0% to 90%; the median was 10%. A total of 47 of the 50 participants scored less than 50%. This is the number of participants for whom System 1 is not dominant over System 2. Clearly belief bias is not present and the hypothesised dominance of System 1 over System 2 has not occurred. Further evidence that participants have typically chosen in accord with logical validity comes from neutral trials. Logically correct responses were chosen to 90% of neutral problems, which was well above chance at 50%. Because the high proportion of logically valid responses to conflict trials it was not possible to explore response time differences between System 1 and System 2 responses to conflict trials.

7.2 Mental Rotation Results

Figure 7.1

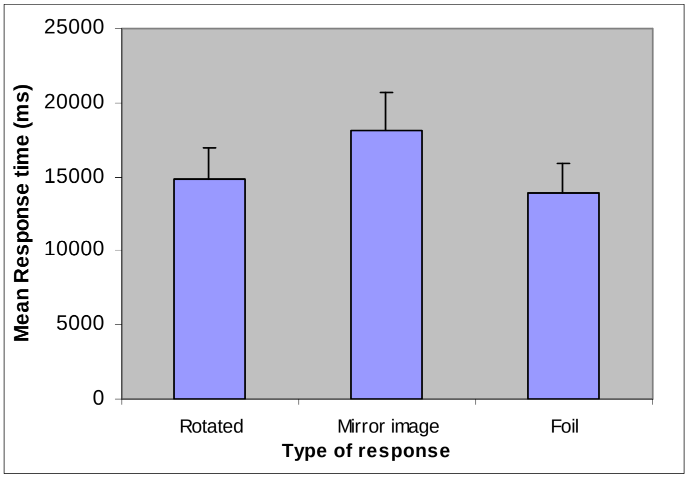
Mean Percent for Each Type of Response to Mental Rotation Tasks



It was hypothesised that System 1 responses (selection of the aligned mirror image alternative) would dominate in the visual spatial reasoning task. Contrary to the hypothesis significantly more correct rotated image alternatives (mean = 67.2%, SD = 22.83) than mirror image alternatives were selected (mean = 21.1%, SD = 20.46), $t(49) = 7.75$, $p<0.001$ 2-tail).

Figure 7.2

Mean Response Times (ms) for Each Type of Response During the Mental Rotation Task

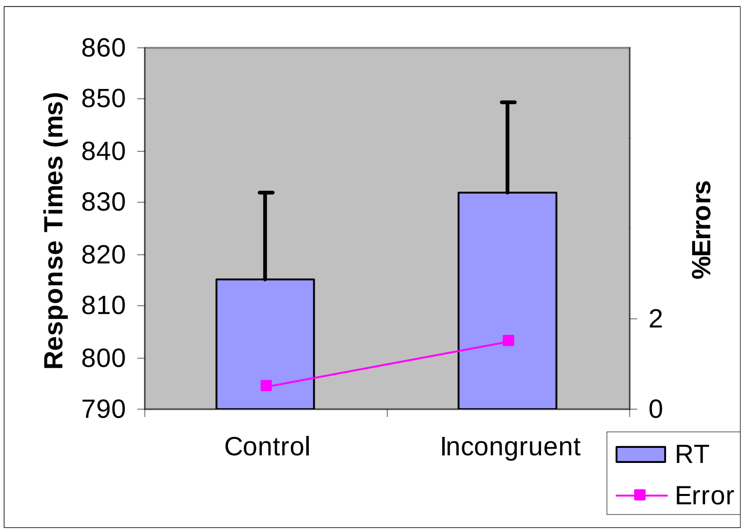


It was expected that incorrect mirror image choices would be made more quickly than correct rotated versions of the standard. A total of eight participant response times to rotated and mirror images were not included in this analysis, as seven participants made no mirror image responses and one response time contained an outlier affecting the group mean. Contrary to expectation response times to rotated images (Mean = 14.8 s., SD = 58.7 s) were significantly faster than response times to mirror images (Mean =18.1 s , SD =12.2 s, $t(41) = -2.25$, $p<0.05$ 2-tail).

7.3 Stroop Results

Figure 7.3

Percent of Colour Errors and Mean Response Times (ms) to Control and Incongruent Stroop Tasks.



Analysis of the Stroop data revealed that there were more errors and slower RTs to incongruent colour words than to control letter strings. Font colours were incorrectly identified on fewer than 1% of trials, such errors occurred approximately twice as often to incongruous colour names (mean = 1.2%, SD = 1.5%) than to control strings of X's (mean = 0.5%, SD = 0.7%), $t(47) = 3.07$, $p<0.01$ 2-tail). Response times to control stimuli were faster (mean = 815 ms, SD = 120 ms) than response times to incongruent stimuli (mean = 832 ms, SD = 122 ms). This difference was close to significance, $t(49) = 1.97$, $p = 0.055$ 2-tail).

7.4 Correlation of System 1 Responding with Stroop Inhibition Scores.

It was expected that people with weaker inhibitory potential would make more System 1 (associative errors) and fewer System 2 (analytical) responses in deductive reasoning. Stroop interference scores were obtained by calculating the difference between median incongruent and control RTs for each participant and the raw difference and difference as a proportion of average RT were calculated. Since the two measures produced very similar results only analyses involving the raw differences hereafter called inhibitory control scores are reported. High inhibitory control scores measured larger differences between Incongruent minus Control response times suggesting weaker inhibition. It was, therefore, expected that bigger System 1 conflict deduction scores would be associated with larger Stroop difference scores. The correlation between inhibitory control scores (Inhibitory control = incongruent-control) (Appendix C) and number of System 1 responses to conflict trials was not significant (*r*=-0.19, p=0.29).

It was also expected that weaker inhibitory control would be related to more System 1 (mirror image) and fewer System 2 (rotated) responses in visual spatial reasoning. A measure of System 1 strength (Number of mirror images/(mirror image plus rotation)) was compared with inhibitory control. The System 1 strength ranged between 0 (all rotations) to 1 (all mirror images). No significant association was found between inhibitory control scores in the Stroop task and percent of System 1 scores the mental rotation task (Diff and System 1 *r*=0.21, p= 0.24).

8.0 Discussion

8.1 Summary of Results

Three hypotheses were tested in the present study. Firstly, for deductive reasoning a dominance of System 1 over System 2 responding was hypothesised. The analysis, however, revealed a higher proportion of System 2 than System 1 responses to deductive reasoning trials. The second hypothesis was that more people would make System 1 responses than System 2 in visual spatial reasoning tasks, yet the mental rotation analysis revealed significantly more rotated image than mirror image responses. It was also expected that System 1 responses would be made more quickly than System 2, but contrary to expectation, response times to rotated images were significantly faster than response times to mirror images. Thirdly, it was hypothesised that people with weaker inhibitory potential would make more System 1 and fewer System 2 responses in both deductive and visual-spatial tasks, but no association was found between inhibitory control and System 1 responding in either task. Although these results were not significant there was a tendency for a greater frequency of System 1 errors to occur among those with less inhibitory control, and for more correct System 2 choices to be made by those with stronger inhibitory control.

It is possible the hypothesis that System 1 would dominate System 2 reasoning for deductive reasoning was not supported because the tasks were too easy for University students. This is consistent with Stanovich and West (2000) who found that general cognitive ability is associated with the ability to resolve belief bias. Additionally, Evans (2002) claims that conclusion believability is clearly irrelevant to the logical task and should have no influence if people were reasoning logically. In similar previous studies, confusion over syntax and the nature of the quantifiers used in the premises have led to lower rates of logic based responding (Evans, 2002). Poor instructions have also been responsible for lower rates of logic based responses. The high proportion of System 2 responding in the current study could indicate that the task was relatively free of attributes which while unrelated to logical form may nevertheless complicate the task resulting in higher rates of System 1 responding. That is the absence of poor instructions or confusion over syntax may have assisted System 2 responding. Nevertheless variability between participants in levels of

System 1 responding did occur sufficiently often to allow analysis and comparison with measures of inhibitory control. Despite this, there was no significant correlation with inhibitory control.

For the mental rotation task, there was also a higher proportion of System 2 responses and it is possible that attributes to a System 1 bias and unrelated to the logical task were also effectively controlled. For instance, the instructions were clear, there was little confusion in the presentation, and there was a clear separation between the tasks required to make System 1 and System 2 responses. System 1 responses were more likely than filler responses suggesting that the selection of a mirror image response represented a possible System 1 bias, as opposed to a general error response. Although there was sufficient variability in the rates of rotation choices among participants, the correlation with Inhibitory Control was not significant and there was no strong support for the hypothesis.

8.2 Methodological Limitations

The findings from the present results are not statistically reliable. For both the Deductive reasoning and Mental rotation task there were very few System 1 responses. This important lack of availability of System 1 responses to compare with variations in inhibitory control, may have affected the significance of correlations between these variables. Further studies may need to provide reasoning tasks with a higher cognitive demand, so as to increase the potential for System 1 responding. By imposing some memory load on the reasoning task, System 1 responding could potentially increase. Also by developing more difficult or complex tasks, imposing a dual task requirement, or by adding a peripheral visual, or auditory distracter System 1 responding could potentially increase. The deductive reasoning task had very few System 2 control tasks to compare System 2 with System 1 reasoning in the conflict trials, so further tasks would improve with the addition of more belief neutral control items. With only 50 participants, the statistical power of the study was relatively low and any measurement effect struggled to reach significance. The Stroop effect was not precise because of limited participant numbers and possibly the inherent variability in the cursor task. A well practiced key press or a voice response may have provided a more sensitive and precise measure of Stroop interference.

Inhibitory control was not significantly correlated with System 1 or System 2 processing in the spatial task. It seems likely that the mental rotation task was not as effective at measuring and capturing the relationship between inhibitory control and reasoning response. This is possibly due to the nature of the visual display in the mental rotation task. Further studies might include alterations to the design of a spatial task, which might more effectively capture a potential relationship between inhibitory control and System 2 responding. A new visual-spatial task that requires participants to compare pictorial displays similar to those elicited in mental imagery during the deductive reasoning task, could provide a more effective comparison with the deductive reasoning measures. Also a timer in the corner of the display might induce faster responding and a higher System 1 response rate. A dual task, requiring a higher memory load might also facilitate increased System 1 response rates in the mental rotation task.

8.3 Implications for Inhibitory Control in Reasoning

According to Friedman and Miyake (2004), studies that rely on difference scores have a tendency to reduce reliability between measures, as different versions of the task that differ in inhibitory requirements may increase measurement error (Friedman and Miyake, 2004). It is therefore, possible that the inhibitory control required for System 2 processing is different to the type of inhibitory control required for the Stroop task. Non significant correlations might also occur because individual tasks may not be tapping into inhibition related functions (Friedman and Miyake, 2004). According to this contention, it is possible that the present findings suggest that System 2 may not require inhibitory control to over ride System 1. This view, however, seems unlikely and contradicts Handley et al.'s (2004), findings that inhibitory control processes are related to the ability to over ride prior belief in favour of logic in deductive reasoning.

Friedman and Miyake (2004) also suggest that non significant correlations between inhibition related functions are typical and offer several additional explanations which have various implications for the presence of inhibitory control in the comparison tasks. Practice effects might cause a reduction in reliability, which could lead to non significant results. While novel tasks impose high attentional control demands, once the tasks have become well practised idiosyncratic strategies may develop to cope with the task demand, reducing reliability of the measures (Friedman and Miyake, 2004).

Shilling, Chetwynd, and Rabbitt (2002) also found zero order correlations when they investigated construct validity across four measures of inhibition in a sample of 49 older adults. They compared four variants of the Stroop task that used colour words, figure-ground stimuli, numbers, and arrows. The correlations between the Stroop interference effects on the four tasks ranged from -.13 to .22 and were all non significant. They concluded that these tasks had no convergent validity and that any common inhibition ability was probably obscured by the idiosyncratic demands of each task. A large proportion of the variance in each task may reflect individual variations in other idiosyncratic requirements with only a small proportion of the variance actually capturing variation in inhibitory control processes (Friedman and

Miyake, 2004). Similarly it seems likely that in the current study the distinctive features pertaining to each task obscured any possible measure of shared inhibitory control.

8.4 Implications for Dual Processing Theory

The present study did not achieve a belief bias effect and was unable to find an association between inhibitory control and System 1 or System 2 reasoning. Previous studies (Evans, 2001; Goel and Dolan, 2004; Handley et al., 2004) have typically used these measures as behavioural evidence to support Dual processing theory. Thus, according to these measures, the present study was unable to find behavioural evidence to support dual processing theory.

Dual processing theory (Goel et al., 2000) proposes, however, that subjects may reason by either engaging a System 1 associative mechanism or consciously engage in a System 2 mechanism. It is therefore possible, that the lack of behavioural evidence to support dual processing theory was due to the high rate of System 2 reasoning. The design of the tasks elicited either System 1 or System 2 responding and it could be argued that because the System 2 processing was consciously engaged that this remained activated throughout the trials for most participants, resulting in a low System 1 response rate. The low System 1 responding may have then reduced the correlation with inhibitory control. Dual processing may well have occurred, but the relationship between inhibitory control and the ability to override System 1 reasoning in favour of System 2 was not supported from the current findings.

Dual Processing theory broadly defines a System 1 response as any rapid, automated, unconsciously processed implicit response and System 2 as any slow, effortful, consciously processed response. It is possible that the engagement of two processing Systems still occurred during task engagement and Dual Processing theory may be able to explain the high rate of System 2 responding in both tasks. Dual process theory proposes that reasoning about different types of spatial information may engage dissociable brain mechanisms. According to Goel, Makale, and Grafman (2004) meaningful familiar material engages a left hemisphere temporal lobe system and reasoning about meaningless unfamiliar material recruit a bilateral parietal system. Goel et al., (2004) argue that participants' reasoning depends on situation specific heuristic processes based on background knowledge and experience. When no heuristics are available as in reasoning about unfamiliar situations, formal methods recruit a frontal-parietal visuospatial system. It is possible that the complexity and unfamiliar visuo-spatial display in the present study engaged System 2 processing and that the mirror image display was not sufficiently familiar to engage System 1 processing. While prior belief is considered sufficient to modulate System 2 reasoning (Goel and Dolan, 2003) the engagement of two distinct brain systems may primarily be a function of the presence or absence of meaningful content. The arbitrary content in the Mental rotation task may have recruited the System 2 reasoning processes and the absence of meaningful content may have been linked to the reduced System 1 responding.

8.5 Mental Models Theory

Dual Processing and Mental models theories were developed to answer different questions, so they each have a different focus. While Dual processing places an emphasis on System 1 and System 2 and reasoning through language processing, the Mental Models approach focuses on the internal models that everyone has of the world and reasoning through visual-spatial processing. The mental models approach (Johnson-Laird, 2005) proposes that participants have internal representations of a logical argument which preserve the structural properties of the world that the sentences are about (Goel et al., 2000). This approach suggests that spatial reasoning serves as a basis for the abstract knowledge and inference required for deductive reasoning (Tversky, 2005). The mental rotation task required the transformation of internalised visual images of the standard to match the external target response. Mental models theory, therefore, fully explains the System 2 response for both tasks. The current findings, therefore, provide support for Mental model theory, but were less able to demonstrate support for Dual processing theory as typically evidenced by a belief bias effect or an association between lower inhibitory control and System 1 processing.

8.6 Future Directions

The current investigation into the relationship between inhibitory processing and System 1 and System 2 processing in Deductive and Spatial reasoning was an experimental process which required a new task design. The mental rotation task was designed to capture and measure System 1 and System 2 processing in spatial reasoning. Future investigations would need to further develop a task that could more effectively capture and measure the presence of System 1 and System 2 in spatial reasoning. A design that could elicit a higher System 1 response rate might possibly be achieved with an on screen timer to induce speeded responses, or with the addition of a dual memory task to increase cognitive load. Further developments to improve the effectiveness of the Stroop task may include higher participant numbers, more deductive tasks including more neutral control trials and a voice response or well practiced key press, or the addition of a peripheral visual, or auditory distracter Although there was some support for the current hypothesis from the results of the present study, with an improved experimental design, the relationship between inhibition and System 1 and System 2 in spatial reasoning could be better confirmed.

A stronger association between inhibitory control and System 2 reasoning would need to be established before any conclusions can be drawn. Latent variable analysis, a statistical technique suggested by Friedman and Miyake (2004) could more effectively capture the common variance associated with inhibitory control, by creating a model of the underlying functions that contribute to each task and excluding variance attributable to idiosyncratic task requirements. If a stronger association was found between inhibitory control and System 1 and System 2 spatial reasoning, then the direction and causality of this relationship could be investigated. Further investigations would also need to establish whether an association between inhibitory control and System 1 and System 2 spatial reasoning is mediated by the presence of other variables, such as working memory, cognitive load or visual attention. If System 1 and System 2 are involved in Spatial reasoning, then everything that people see would be reasoned about according to whether they are using System 1 or System 2.

9.0 Conclusion

People tend to vary in inhibitory control processes and might reason either according to System 1 and System 2. This study verified that when instructions and logic requirements are clear and the participant sample is high in general cognitive ability, belief bias may not occur (Handley et al., 2004; Evans, 2003; Stanovich and West 2000). This study opens the way for future understanding of the processes involved in System 1 and System 2 reasoning and the possibility that inhibitory control could potentially be associated with System 1 and System 2 in spatial as well as deductive reasoning. By adapting the mental rotation task to become a multi-choice version including System 1 (mirror) and System 2 (rotated image) responses this initiated the development of a potential method for testing the presence of System 1 and System 2 reasoning in a spatial format. Due to the differing idiosyncratic demands of each task which may have obscured any common variables associated with inhibitory control, the present study was unable to capture any possible relationship between individual variations in inhibitory control and System 1 and System 2 reasoning.

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Appendix A
Deductive Reasoning Problems

1. **Believable Valid** Whales are bigger than dolphins. Dolphins are bigger than goldfish *So, are whales bigger than goldfish?*	2. **Believable Invalid** Dunedin is North of Christchurch. Christchurch is North of Wellington. *So, is Wellington North of Dunedin?*
3. **Believable Invalid** Basketballs are bigger than tennis balls. Golf balls are bigger than Basketballs. *So, are tennis balls bigger than golf balls?*	4. **Unbelievable Valid** Wellington is North of Christchurch Dunedin is North of Wellington. *So, is Dunedin North of Christchurch?*
5. **Unbelievable Valid** Cricket balls are bigger than golf balls. Golf balls are bigger than rugby balls. *So, are cricket balls bigger than rugby balls?*	6. **Unbelievable Invalid** Goldfish are smaller than dolphins. Dolphins are smaller than whales. *So, are whales smaller than goldfish?*
7. **Believable Invalid** Timaru is bigger than Auckland. Christchurch is bigger than Timaru. *So, is Auckland bigger than Christchurch?*	8. **Unbelievable Valid** Walking is faster than flying. Driving is faster than walking. *So, is driving faster than flying?*
9. **Neutral Valid** Nids are bigger than Yigs. Yigs are bigger than gons. *So, are Nids bigger than gons?*	10. **Neutral Invalid** Dambles are stronger than Heagles. Heagles are stronger than Ringoes. *So, are Ringoes stronger than Dambles?*
11. **Neutral Indeterminate** Bappeds are happier than Zingles. Wabs are happier than Zingles. *So, are Bappeds happier than Wabs?*	12 **Neutral Indeterminate** Skibs are faster than Hedobs. Skibs are faster than Febozs. *So, are Hedobs faster than Febozs?*

13. **Believable Valid** Cars run on petrol. All things that run on petrol carry people. *So, do cars carry people?*	14. **Believable Invalid** Cows have four stomachs. Animals with four stomachs are not heavy. *So, are cows heavy?*
15. **Believable Valid** Horses have hooves. Animals that live near farms have hooves. *So, do horses live near farms?*	16. **Believable Valid** Teeth are made of calcium. Things that help us eat are made of calcium. *So, do teeth help us eat?*
17. **Unbelievable Valid** Children read books. People who read books are neurosurgeons. *So, are children neurosurgeons?*	18. **Unbelievable Invalid** Carrots are vegetables. Vegetables do not grow on trees. *So, do carrots grow on trees?*
19. **Unbelievable Indeterminate** Bees fly in the sky. Insects that live on mars fly in the sky. *Do bees live on mars?*	20. **Unbelievable Invalid** Dogs bark. Animals that do not bark have two legs. *So, do dogs have two legs?*
21. **Unbelievable Valid** Deer have antlers. Animals with antlers have four teeth. *So, do deer have four teeth?*	22. **Believable Invalid** Rock stars drive to work. People who drive to work do not like loud music. *So, do rock stars like loud music?*
23. **Believable Indeterminate** Surgeons work a lot. Wealthy people work a lot. *So, are surgeons wealthy?*	24. **Believable Indeterminate** Sunflowers are grown in fields. Things that contain chemicals are grown in fields. *So, do sunflowers contain chemicals?*

Appendix B

Presentation Stimuli Used in the Mental Rotation Task.

Instruction: Rotated B, Mirror D { EMBED PowerPoint.Slide.8 }	2 Rotated C, Mirror A { EMBED PowerPoint.Slide.8 }
1 Rotated C, Mirror B { EMBED PowerPoint.Slide.8 }	4 Rotated A, Mirror B { EMBED PowerPoint.Slide.8 }
3 Rotated D, Mirror C { EMBED PowerPoint.Slide.8 }	5 Rotated D, Mirror A { EMBED PowerPoint.Slide.8 }

6 Rotated D, Mirror B { EMBED PowerPoint.Slide.8 }	7 Rotated B, Mirror C { EMBED PowerPoint.Slide.8 }
8 Rotated C, Mirror B { EMBED PowerPoint.Slide.8 }	9 Rotated C, Mirror A { EMBED PowerPoint.Slide.8 }
10 Rotated A, Mirror C { EMBED PowerPoint.Slide.8 }	11 Rotated D, Mirror A { EMBED PowerPoint.Slide.8 }

12 Rotated A, Mirror C { EMBED PowerPoint.Slide.8 }	13 Rotated D, Mirror A { EMBED PowerPoint.Slide.8 }
14 Rotated C, Mirror B { EMBED PowerPoint.Slide.8 }	15 Rotated B, Mirror C { EMBED PowerPoint.Slide.8 }
16 Rotated B, Mirror A { EMBED PowerPoint.Slide.8 }	17 Rotated A, Mirror C { EMBED PowerPoint.Slide.8 }

Appendix C

Correlation Matrix Comparing Reasoning and Stroop Responses

Reasoning Variables	RT Control	RT Incong	Diff = Incon-Co	Diff/ Control	Err Control%	Err Incong%
Deductive						
Sys 1	.2283	.1433	-.1886	-.2188	.3694	-.0548
	p=.201	p=.426	p=.293	p=.221	*p=.034	p=.762
Corr Neut	-.0917	-.0993	-.0744	-.0833	-.0130	-.2231
	p=.612	p=.582	p=.681	p=.645	p=.943	p=.212
Corr-Sys 1	.0699	.0067	-.1916	-.2196	.2338	-.2352
	p=.699	p=.971	p=.286	p=.220	p=.190	p=.188
Mental rotation						
% Rotate	-.1250	-.1622	-.1976	-.2107	-.3301	-.2328
	p=.488	p=.367	p=.270	p=.239	p=.061	p=.192
% Mirror	-.0124	.0550	.2357	.2661	.1685	.0532
	p=.945	p=.761	p=.187	p=.134	p=.349	p=.769
% Foil	.2904	.2353	-.0493	-.0821	.3662	.3888
	p=.101	p=.187	p=.785	p=.650	*p=.036	*p=.025
S1strength	.0285	.0833	.2115	.2367	.2368	.1265
	p=.875	p=.645	p=.237	p=.185	p=.185	p=.483
RT Rotate	.1537	.1120	-.0713	-.0861	-.2859	-.0331
	p=.393	p=.535	p=.694	p=.634	p=.107	p=.855
RT mirror	.1356	.1190	.0100	-.0011	-.1815	.0984
	p=.452	p=.509	p=.956	p=.995	p=.312	p=.586
RT foil	.2183	.1440	-.1553	-.1811	-.2759	-.0156
	p=.222	p=.424	p=.388	p=.313	p=.120	p=.931

* Significant at $p < 0.05$ (N=50)