EMBODIED COGNITION, COGNITIVE STRATEGIES, AND GENDER DIFFERENCES IN MENTAL ROTATION PERFORMANCE

by

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B.A. (Honours), University of New Brunswick, 2009

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

Doctorate of Philosophy

in the Graduate Academic Unit of Psychology

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This dissertation is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

June, 2015

ABSTRACT

On average, men outperform women on mental rotation tasks. The aim of Article I was to re-examine previous findings in which the magnitude of the male advantage in mental rotation abilities increased when participants mentally rotated occluded versus non-occluded items, and decreased when participants mentally rotated human figures versus blocks. Mainly, the study aimed to address methodological issues noted on previous human figure mental rotation tests as the block and human figure test items used were likely not equivalent in terms of their cognitive requirements. Results did not support previous research on embodied cognition as mental rotation performance decreased among both men and women when mentally rotating human figures compared to blocks. However, for women, the effect of occlusion was decreased when mentally rotating human figures. Results are discussed in terms of task difficulty and gender differences in confidence and guessing behavior. The aim of Article II was to provide a better understanding of participants reduced accuracy when rotating human figures compared to blocks reported in Article I, and the role of image familiarity, embodied cognition and cognitive strategies on gender differences in performance when rotating blocks and bodies. Two new mental rotation tests were created: one using photographs of real human models positioned as closely as possible to computer drawn figures from the human figures mental rotations test used in Article I, and one using analogous block figures. It was hypothesized that when compared to the analogous blocks, the real human figures would lead to improved accuracy among both men and women, a reduced magnitude of gender differences in accuracy, and a reduced effect of occlusion on women's accuracy when compared to analogous block figures. The three-way interaction between test, gender and occlusion reported in Article I was not replicated. However, women's scores on the real human figures improved more than men's scores on the real human figures test compared to the block figures test. This finding points to a greater strategy shift among women than men when rotating human figures. Results suggest that individuals struggling with mental rotation may benefit from training that encourages embodied cognition and holistic processing.

DEDICATION

"We cannot all succeed when half of us are held back."

– Malala Yousafzai

This dissertation is dedicated to women everywhere who are pursuing careers in science, technology, engineering, and mathematics. May your intelligence and perseverance inspire all women who follow in your footsteps.

ACKNOWLEDGEMENTS

Thank you to my examining board, Dr. Erik Scheme, Dr. Usha Kuruganti, and Dr. Gerianne Alexander, for their stimulating questions. Thank you to Dr. K. Troy Harker, and Dr. Lisa Best, for reading over numerous drafts of my dissertation and providing so many helpful comments and suggestions.

Thank you to my parents, Kevin and Barb, for their unending love and support throughout this process. Thank you to my husband, Michael, for high-fiving significant results and accepted papers, letting me vent when studies went awry or I received tough reviews, making me supper and making sure I ate it when I was under a deadline, and hugging me when I felt I was "never going to finish". You never stopped believing in me and encouraging me. I love you to the moon and back.

Finally, thank you to Dr. Daniel Voyer. Thank you for peaking my interest in the field of psychology when you taught the *Introduction to Psychology* class that I fatefully enrolled in ten years ago. Thank you for taking a chance on me during my second year of university and hiring me to work in your lab. Thank you for taking me on as an honours student, and then continuing to guide me as a PhD student. Thank you for showing me what a dedicated and prolific scholar looks like. Thank you for never lowering your expectations of me or my work. Thank you for making me the envy of all other graduate students with your unparalleled turn-around times. Thank you for teaching me the difference between “effect” and “affect”. Thank you for making me laugh on those days that I could have just as easily cried. You have been a teacher, a mentor, a cheerleader, a career counselor, a disciplinarian when I needed it, and most importantly, a friend. Data, data, data, data, data, data, data, data, Batman!

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CHAPTER I

General Introduction

Spatial abilities are essential to humans. We use these abilities in a multitude of everyday tasks, including when we manipulate visual stimuli in our imagination, complete difficult math problems, and navigate through our environment. Gender differences in spatial performance have been well established with men, on average, performing better on spatial tests than women, particularly on mental rotation tasks that require participants to rotate a mental representation of stimuli presented (further description below; Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). The implications of gender differences on spatial tasks are widespread. Most notably, performance on spatial tests has been correlated with mathematics achievement (Reuhkala, 2001; Rosselli, Ardila, Matute, & Inozemtseva, 2009), and quantitative performance on high stakes standardized tests (Bridgeman & Wendler, 1991; Casey, Nuttall, Pezaris, & Benbow, 1995). Success on standardized tests such as the mathematics subtest of the Scholastic Aptitude Test is crucial to gain entry into science, technology, engineering, and mathematics (STEM) fields, particularly in the United States. Gender differences in spatial ability may help to explain the disproportionately higher number of men in comparison to women in the STEM fields, both as students and professionals (Beede, Julian, Langdon, McKittrick, & Doms, 2011; Ferguson, & Zhao, 2013). The gender gap in STEM fields goes beyond gender differences in academic enrollment. In their summary of United States women in STEM fields, Beede et al. (2011) noted that women in the United States hold a disproportionally low share of STEM degrees, women who hold STEM degrees are less likely than their male counterparts to go on to work in STEM fields, and, although women make up roughly 50% of the US workforce, women hold less than 25% of STEM jobs.

The gateway to these important, high paying STEM careers is, of course, a STEM degree, and the gateway to a STEM degree is acceptance into undergraduate and graduate degree programs. Admission to these programs often hinges on students' math grades and performance on high stakes tests such as the mathematics subtest of the Scholastic Aptitude Test. If women's reduced spatial abilities have a negative impact on their math and Scholastic Aptitude Test scores (Casey, Nuttall, Pezaris & Benbow, 1995) , it follows that helping women improve their spatial skills, and subsequently improve their autonomous math performance and Scholastic Aptitude Test scores (Kimball, 1989), could help to reduce the gender gap in STEM fields. To develop effective spatial skills training programs, we need to better understand gender differences in spatial ability and uncover the factors that account for gender differences, particularly in mental rotation where the largest gender differences are found (Linn, & Petersen, 1985; Voyer, Voyer, & Bryden, 1995).

Gender Differences in Spatial Ability

In their review of the literature, Maccoby and Jacklin (1974) reported that the male advantage on tests of spatial ability, particularly visual-spatial skills, starts to appear consistently at the beginning of adolescence. Linn and Petersen (1985) used meta-analytic techniques to precisely quantify gender differences in spatial ability. Focusing on similarities in the processes that participants use when completing different tests, Linn and Petersen proposed three categories of spatial ability: spatial perception, spatial visualization, and mental rotation. Spatial perception tests were defined as tests that had participants determine spatial relationships in relation to their own bodies, despite distracting information. Spatial visualization tests were defined as tests that require complex, multi-step manipulation of spatially presented information, such as finding a simple figure embedded in a more complex figure. Finally, mental rotation tests were defined as tests that measure an individual's ability to mentally rotate two dimensional (2D) or three dimensional (3D) stimuli, involving a Gestalt-like analogue process (see below for extensive review). Although it is not the focus of this dissertation, it is worth noting that, on average, gender differences in the spatial skill of object location memory favour women (see Voyer, Postma, Brake and Imperato-McGinley (2007) for an extensive review of the literature).

Linn and Petersen found that males had higher spatial perception performance beginning at age eight that continued into adulthood, with a larger magnitude of gender differences after the age of 18. They did not find significant gender differences in spatial visualization performance at any point in the lifespan. Most relevant to the current thesis, Linn and Petersen's (1985) meta-analysis showed that large gender differences in favour of males on the Vandenberg and Kuse (1978) test of mental rotation, and moderate gender differences on the Primary Mental Abilities (PMA) space test (Thurstone, & Thurstone, 1941) were found across age groups. The authors suggested that the difference in the magnitude of the gender differences in performance on the Vandenberg and Kuse Mental Rotations Test (MRT) and performance on the PMA space test may be due to the increased complexity of the Vanderberg and Kuse items (see Figure 1 on page 122 for an example from each test). In addition, Linn and Petersen pointed out that women may be more likely to utilize a less successful piecemeal (i.e., analytic) strategy when mentally rotating stimuli; this piecemeal strategy may be effective on the primary mental abilities space test but would be less effective on the complex items presented on the Vandenberg and Kuse items. This finding fits with Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) who reported that males using global processing (e.g. rotating entire block figure as a whole) performed better on the MRT than males who reported using a piecemeal strategy (e.g. rotating parts of the block figure separately). As a final note, Peters et al. suggested that future researchers aiming to better understand gender differences in specific spatial abilities should investigate the cognitive processes used when attempting rotation of specific item types.

A decade later, Voyer, Voyer, and Bryden (1995) published a meta-analysis that followed up Linn and Petersen's (1985) meta-analysis. Voyer et al.'s meta-analysis also aimed to challenge recent reports that gender differences in spatial ability were small and inconsistent (Caplan, MacPherson, & Tobin, 1985), and that gender differences were disappearing over time (Feingold, 1988). Voyer et al. (1995) showed that among the spatial tasks included in their study, gender differences in mental rotation were largest ($d = 0.56$), gender differences in spatial perception were smaller yet still statistically significant ($d = 0.44$), and spatial visualization tasks did not show consistent gender differences ($d = 0.19$). Voyer et al. replicated Linn and Petersen's (1985) finding that the magnitude of the gender difference in spatial performance is largest on the Vandenberg and Kuse MRT, particularly when this test is scored out of 20 (one point allotted only when both correct alternatives on an item were identified) as opposed to 40 (one point allotted for any correct alternatives identified), with men scoring on average 0.94 standard deviations higher than women. Voyer et al.'s analysis also showed that gender differences in mental rotation did not appear to be decreasing over time. Recent work by Quinn and Liben (2014) suggests gender differences in mental rotation are present from as early as three months of age.

Given the well-established gender differences in mental rotation, it is important to review this spatial skill more specifically. As mentioned earlier, of all spatial abilities, gender differences in mental rotation are largest. But what exactly is mental rotation, and how is this spatial ability measured?

Mental Rotation. The mental rotation task most commonly used today was originally developed by Shepard and Metzler (1971) to determine whether participants' response times (RT) were a function of the angular difference between 3D block figures. Shepard and Metzler had eight adult participants indicate whether a pair of block figures were the same, but rotated from 0° to 180° (at 20° intervals), or whether the figures were mirror images of one another. Each participant was presented with 1600 pairs of block figures. Shepard and Metzler found that when the two block figures were the same, participants' RTs increased as the difference in the angle of rotation between the two block figures increased; the greater the angular difference between the two figures, the longer it took participants to indicate that the two figures were the same. This elegant experiment provided evidence that mental rotation likely involves rotating a target figure in one's mind to determine whether it can be rotated to match a comparison figure. Principally, Shepard and Metzler provided evidence that humans engage in analog spatial processing, and there is a one-to-one relationship between internal and external rotation of stimuli.

Vandenberg and Kuse (1978) later used the 3D block figures from this mental rotation task (Shepard, & Metzler, 1971) to develop a paper-and-pencil version of the task, which they called the Mental Rotations Test (MRT). This paper-and-pencil MRT displayed high internal consistency (Spearman-Brown = .79), high test-retest reliability (r = .83), and high construct validity as the MRT was highly correlated with other tests presumed to measure spatial abilities and was not highly correlated with verbal tasks. A male advantage was found across age groups tested (ages 14 to 53 years).

Peters et al. (1995) revised the original pen-and-paper test using a computer-assisted drawing program and this is the version of the test that most researchers use today. Peters et al. validated their test by asking 636 undergraduate students enrolled in science and arts programs to complete their re-drawn MRT. Participants were given three minutes to complete the first 12 MRT items, followed by a four minute break, then three minutes to complete the final 12 MRT items. Peters et al. found that, consistent with Vandenberg and Kuse's (1978) findings, males outperformed females on this re-drawn MRT, with gender accounting for 17.7% of the variance in scores. A subset of 54 males and 47 females completed both the redrawn MRT and two other tests of spatial ability (Picture Folding Test and the Card Folding Test). Males had higher means on each test, yet the redrawn MRT was the only test that yielded significant gender differences in performance. In examining strategies used to complete the MRT items, Peters et al. reported only one noteworthy strategy difference: males who reported that they rotated parts of the block figure performed significantly worse than males who reported rotating the entire block figure as a whole. Essentially, among male participants, global processing resulted in better mental rotation performance than piecemeal processing.

A recent study examining gender differences in mental rotation and line angle judgment tasks across 53 nations showed that the male advantage on mental rotation (*d*s = .47) and spatial perception (*d*s = .49) tasks persists (Lippa, Collaer, & Peters, 2010). Lippa et al. used participant responses to an online BBC survey including a short, six item MRT (Peters et al., 1995) and a 20 item line angle judgment task (Collaer, 2001). The authors found that gender differences in spatial performance were consistent across nations.

Why do these gender differences in mental rotation exist? And why are they larger than gender differences in other spatial abilities? The present dissertation examined some potentially relevant factors related to cognitive processing.

Factors Associated with Gender Differences in Mental Rotation

Popular explanations of gender differences in mental rotation offered in the research literature include biological factors, environmental factors, test characteristics, and strategy factors. As it includes most of these factors, Sherman's (1967) Bent Twig Theory provides an excellent framework for investigating gender differences in spatial ability. Sherman suggested that, like the old adage "as the twig is bent, so the tree shall grow", innate biological predispositions in children, like bends in twigs, may cause different patterns of interaction with the environment, altering the direction of growth of abilities in a child. Therefore, initially small biological gender differences may interact with environmental factors, developing into large gender differences later in life.

Biological factors. Some of the biological factors that researchers have associated with gender differences in spatial ability include differences in brain structure and functioning, differences in prenatal and circulating hormones, and genetic gender differences.

Brain structure and functioning. Gender differences in brain structure and functioning have been examined to help explain gender differences in spatial ability. For example, Jordan, Wüstenberg, Heinze, Peters, and Jäncke (2002) used functional magnetic resonance imaging (fMRI) to study the cortical activation of men and women during a mental rotation task. Jordan et al. found that men had higher activation in the primary motor cortex and women had higher activation in the inferior temporal gyrus. Jordan et al. argued that these differences suggest that men may use a more "hands on" approach to mental rotations and engage the primary motor cortex to imagine physically moving the items, whereas women may use a more piecemeal strategy when mentally rotating items as the inferior temporal gyrus is involved in object-part identification. It is noteworthy that this finding fits nicely with Linn and Petersen’s (1985) suggestion and Peters et al.’s (1995) finding that global, holistic processing results in greater mental rotation accuracy compared to piecemeal, analytic processing.

Similar findings were reported in an fMRI study by Hugdahl, Thomsen, and Ersland (2006) who found different brain activations in men and women during a mental rotation task, with men showing a significantly higher activation in the right parietal lobe and women showing a higher activation in the right inferior frontal gyrus. Hugdahl et al. suggested that the activation of the right parietal lobe reflects the tendency of males to perceive an object visually as a whole, and that the activation of the right inferior frontal gyrus reflects the female propensity to perceive an object as a combination of its parts. This holistic visual processing among men may help to explain the male advantage on mental rotation tasks, as it is conceivable that mentally rotating figures as a whole is easier than mentally rotating multiple components of a figure separately (e.g., Amorim, Isableu, & Jarraya, 2006; Heil, & Jansen-Osmann, 2008).

Hormones. The effects of prenatal and circulating hormones on behaviour have also been related to gender differences in spatial ability. For example, Hier and Crowley (1982) compared the spatial performance of men who were diagnosed with idiopathic hypogonadotropic hypogonadism, with that of normal control men, and men diagnosed with acquired hypergonadotropic hypogonadism that had developed after puberty. Hypogonadotropic hypogonadism and hypergonadotropic hypogonadism are both conditions that result in a lack of sex steroid production by the gonads. Hier and Crowley found that participants with idiopathic hypogonadotropic hypogonadism scored significantly lower on the Block Design subtest from the Wechsler Adult Intelligence Scale (Wechsler, 1955), the Embedded Figures Test (Witkin, Oltman, Raskin, & Karp, 1971), and the Space Relations subtest from the Differential Aptitude Tests (Bennett, Seashore, & Wesman, 1973) than normal controls and participants with acquired hypergonadotropic hypogonadism. In addition, androgen replacement therapy in six of the patients did not appear to improve spatial performance. These findings point to the impact of androgens on permanent organization of the brain early in development (before puberty), which fits with Berenbaum, Korman and Leveroni's (1995) conclusion that moderate to high levels of androgens during prenatal and early postnatal development are related to increased spatial abilities.

More recent studies have revealed that testosterone may have an enhancing effect on spatial performance after prenatal development and puberty (Courvoisier, Renaud, Geiser, Paschke, Gaudy, & Jordan, 2013; Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Gunturkun, 2000). In a striking experimental study, Aleman, Bronk, Kessels, Koppeschaar and van Honk (2004) found that just four to five hours after a single administration of 0.5 mg of sublingual testosterone, women's performance on a 3D mental rotations test improved compared to women in a placebo group. This finding suggests a causal relationship between testosterone and visuospatial ability.

Genetics. As biological factors have been implicated in gender differences in spatial ability, it is not surprising that some researchers have investigated the role of genetics (e.g., McGee, 1979; Vandenberg, 1969). In this context, Vuoksimaa, Viken, Hokkanen, Tuulio-Henriksson, Rose, and Kaprio's (2010) twin study provided valuable insight into sex-specific genetic effects on spatial ability. Vuoksimaa et al. examined variance in mental rotation performance among monozygotic and dizygotic twin pairs and found that additive genetics accounted for approximately 50% of variance in both males and females mental rotation scores. Therefore, the remaining 50% of the variance in males and females mental rotation scores cannot be accounted for by genetic factors. Like most psychological traits, the development of spatial abilities and gender differences in these abilities would be accounted for by environmental factors, measurement errors, and other biological factors as well. Therefore, it is important not to overlook environmental factors that might affect gender differences in spatial ability.

Environmental Factors. In addition to biological factors, numerous environmental factors have been proposed to explain gender differences in spatial ability, including childhood activities, and sex-role identification.

Childhood activities. Some researchers suggest that the types of activities boys and girls engage in during childhood shape the development of spatial abilities and help to explain gender differences in performance. In a study of four year old boys and girls, Serbin and Connor (1979) found a significant relationship between masculine and feminine play activities and spatial and verbal test scores; both boys and girls who engaged in more feminine activities scored higher on a verbal test and both boys and girls who engaged in more masculine activities scored higher on a spatial test. It is important to note that masculine toys also tend to have a higher spatial content than feminine toys.

In a more recent study, Voyer, Nolan, and Voyer (2000) examined the relationship between gender, university students' reported childhood spatial and non-spatial toy and activity preference, and their performance on the MRT and another spatial perception task (Water Level Test). Voyer et al. found that spatial toy preference was related to improved MRT performance among both males and females; however, a significant male advantage on the Water Level Test only existed among participants who favoured non-spatial toys. There was no gender difference in Water Level Test performance among male and female participants who favoured spatial toys. Voyer et al. suggested that the differences may be due to the fact that the Water Level Test is a knowledge test (knowledge of gravity), and the MRT is an abilities test. In addition, the performance of females on the Water Level Test was not affected by sports preference, yet sports preference was related to improved Water Level Test performance among males. Taken together, Voyer et al. suggested that spatial abilities in males may hinge more on a biological predisposition towards high spatial abilities. Therefore, males' abilities cannot improve to the same extent that the spatial skills of females can improve through experience and training.

Voyer et al. (2000) relied on participant ratings of activities as masculine, feminine, spatial, and non-spatial. Using a more systematic approach, Doyle, Voyer, and Cherney (2012) examined the validity and reliability of the Childhood Activities Questionnaire developed by Cherney and Voyer (2010) that required participants to indicate the amount of time they spent engaging in various masculine spatial, masculine non-spatial, feminine spatial, and feminine non-spatial activities during childhood. Doyle et al. found that, after the effect of gender was accounted for, participants who reported engaging in more spatial activities during childhood exhibited higher visuospatial skills (measured using the Water Level Test) and higher math grades in adulthood. It cannot be denied that masculine childhood activities are typically higher in spatial content than feminine childhood activities (Cherney, & Voyer, 2010). Therefore, sex-role identification may play a role in the activities children choose to engage in, which likely affect the amount of spatial training and experience a child is afforded.

Sex-role identification. Signorella and Jamison (1978) pointed to the role of sex-role orientation in spatial abilities when they reported that the best predictor of the success of adolescent girls on two spatial tasks (Embedded Figures Test and Water Level Test) was a masculine sex-role orientation. Signorella and Jamison believed that this was because girls who had a masculine sex-role orientation were more likely to pursue male-typical experiences and masculine sex-typed activities, which contributed to spatial skills training. In their subsequent meta-analysis, Signorella and Jamison (1986) found further support for the idea that gender role affects spatial performance, as there was a robust positive association between girls' and women's masculinity scores and their spatial performance. Again, the authors noted that this finding may be due to spatial tasks being stereotypically masculine.

Sex-role identity and spatial performance may also be linked to the effect of instruction manipulations and stereotype threats on spatial performance (e.g., McGlone, & Aronson, 2006; Moè, & Pazzaglia, 2006; Nguyen, & Ryan, 2008). When participants experience a stereotype threat they may be influenced to underperform on a task that their in-group stereotypically does not perform well on. In this case, women are the in-group and mental rotation is the task. For example, Sharps, Price, and Williams (1994) found that, although men outperformed women on a 3D Shepard and Metzler (1971) task when the spatial nature of the task was emphasized, there was no gender difference in performance when the spatial nature of the task was not mentioned. Similarly, in a series of experiments, Wraga Duncan, Jacobs, Helt, and Church (2006) found that women exposed to stereotypically positive messages (i.e., women perform better at this task than men) made fewer errors on an imagined self-rotation task than women in a control group who read a neutral message, which could be due to the advantageous effect of a stereotype lift. These authors also found evidence that stereotype threat can affect men's mental rotation performance as men who were exposed to a stereotypically negative message (i.e., women perform better at this task than men) made more errors on the self-rotation task than men who were exposed to a neutral message.

Thus far, only characteristics of the participants have been considered; however, many authors have argued that task and procedural characteristics, typically labeled as "performance factors" (Goldstein, Haldane, & Mitchell, 1990) should also be considered.

Performance Factors. There is evidence that the magnitude of gender differences in mental rotation may be affected by variations in MRT administration other than stereotype priming instruction manipulations. Particularly, there seems to be an effect of timing procedures on gender differences in guessing behaviours and confidence, as well as gender differences in cognitive strategies, and effects related to the types of MRT items presented.

Timing and guessing behaviours. Voyer, Rodgers, and McCormick (2004) examined the possibility that women score lower on the MRT not because they have lower levels of spatial ability, but simply because it takes them longer to mentally rotate stimuli as a result of their slower, cautious working style (Goldstein et al., 1990). To investigate the influence of timing and guessing on gender differences in spatial ability, Voyer et al. administered the MRT to participants item by item, allocating between 15 and 40 seconds per item (inclusive) or an unlimited amount of time. Voyer et al. found that gender differences of a similar magnitude (favouring males) were obtained regardless of timing conditions. This finding suggests that it is level of spatial abilities, not speed of processing, that influences gender differences in spatial scores (Lohman, 1986). However, when more time was available to complete the MRT items, response patterns on items left blank reflected an increased propensity to guess among women. Therefore, the authors proposed that gender differences in spatial performance likely reflect a complex interplay between both level of spatial ability and performance factors. Indeed, Voyer's (2011) meta-analysis showed that, although the magnitude of gender differences in mental rotation is reduced when more time is allotted to complete the task, a male advantage persists across timing conditions. Therefore, it appears that, although women's mental rotation performance improves when given more time, it does not reach the level of men's performance.

Confidence and guessing behaviours. As seen in Voyer et al. (2004), guessing behaviour requires closer examination, and may be linked to confidence. From that perspective, Cooke-Simpson and Voyer (2007) reported that confidence ratings were positively correlated with performance on the MRT, and lower confidence was related to increased guessing behaviour. Perhaps not surprisingly, in their study, men displayed both higher confidence ratings and higher MRT scores than women. Estes and Felker (2012) aimed to provide more direct empirical evidence that confidence influences mental rotation performance. In this study, participants completed a line angle judgment task prior to completing the MRT. Before starting the MRT, participants' confidence was manipulated as they were either told their performance on the line judgment task was above average (high confidence group) or below average (low confidence group). Results showed that participants randomly assigned to the high confidence group performed more accurately on the MRT than participants in the low confidence group, and women in the high confidence group performed as accurately as men in the low confidence group. Estes and Felker noted that confidence levels did not completely explain the magnitude of gender differences in mental rotation performance; therefore, it is important to consider other performance factors that may help to explain these gender differences.

Cognitive Strategies. As previously mentioned, Linn and Petersen (1985) suggested that Gestalt like, global-holistic processing would provide a more effective cognitive strategy during mental rotation than a part-by-part analytic strategy. Furthermore, gender differences have been observed in the cognitive strategies used during mental rotation (e.g., Gluck, & Fitting, 2003; Heil, & Jansen-Osmann, 2008; Peters et al., 1995; Tzuriel, & Egozi, 2010). Specifically, women tend to consider the individual parts or features of a figure and attempt to rotate the resulting piecemeal mental image. Although she did not examine gender differences in mental rotation strategy use, Schultz (1991) created a valid and reliable Spatial Strategies Questionnaire and found that endorsement of holistic strategies (e.g., move object) was predictive of higher spatial visualization scores, and endorsement of analytic strategies (e.g., focus on key features) was predictive of lower spatial visualization scores. As mentioned above, gender differences found in brain activation during mental rotation point to the possibility that men and women utilize different cognitive strategies, with men using a more "hands on" approach to mental rotations, engaging the primary motor cortex to imagine physically moving the items, and women using a more piecemeal process when mentally rotating items as the inferior temporal gyrus is involved in object-part identification (see Hugdahl et al., 2006; Jordan et al., 2002).

Heil and Jansen-Osmann (2008) relied on behavioural data to better understand gender differences in cognitive strategies by presenting participants with simple and complex 2D polygons in a mental rotation task. It was hypothesized that, if men use a more holistic approach to mental rotation, then there should be little difference in RTs when rotating simple and complex polygons, and if women use a more piecemeal approach to mental rotation, then their RTs should be slower when rotating complex polygons compared to simple polygons as complex polygons have more parts to process. Heil and Jansen-Osmann’s hypotheses were supported, with men performing faster when rotating both complex and simple polygons, with an increased gender difference in RTs on complex polygons compared to gender differences when rotating simple polygons.

The importance of gaining a better understanding of the role of cognitive strategies on gender differences in mental rotation is exemplified in Tzuriel and Egozi's (2010) investigation of the impact of spatial strategy training on young children's spatial abilities. Tzuriel and Egozi found that, after children in grade one received Spatial Sense training that emphasized the use of global-holistic strategies rather than analytic strategies when mentally rotating figures, gender differences in mental rotation disappeared, yet differences remained among children in a control group who did not receive training. Furthermore, Tzuriel and Egozi found that it was girls' improved scores after training that closed the gender gap. This suggests that girls who received training typically moved from less efficient strategies to a more beneficial global-holistic strategy. Although gender differences in cognitive strategy may be influenced by spatial training, MRT item types might also affect gender differences in cognitive strategies.

Item Types. Voyer and Hou (2006) were likely the first to analyze individual differences on four item types on the Peters et al. (1995) MRT. These four item types were comprised of items that had mirror distractors, items that had structural distractors, items that had occluded distractors or correct alternatives, and nonoccluded items. Mirror items include distractors that are a mirror image of the target item, whereas structural items include distractors that are structurally different from the target item. Occluded items include correct alternatives or distractors that are rotated in such a way that parts of the item are hidden from view, whereas nonoccluded items include no such occlusion (see Figure 1 on page 72 for an example of each item type). Most of the original MRT items fall into one of four categories: mirror occluded, mirror non-occluded, structural occluded, or structural non-occluded. It is important to note that Voyer and Hou identified two items on the test as mixed items, each comprised of one mirror distractor and one structural distractor. One of these mixed items involved occlusion and the other did not. Considering these various item types, Voyer and Hou hypothesized that, due to the influence of task difficulty, gender differences would be larger for mirror than for structural items, and gender differences would be larger for occluded than for nonoccluded items.

As expected, Voyer and Hou (2006) found decreased accuracy on occluded MRT items for both genders, reflecting the increased difficulty of these items. Moreover, partially supporting their hypotheses, the magnitude of gender differences in mental rotation performance was larger for occluded than nonoccluded items. Voyer and Hou suggested that the increased magnitude of the gender difference in performance on occluded items could reflect the influence of 3D stimuli on gender differences in mental rotation, or simply that the occluded items were more difficult than non-occluded items. The interpretation that occluded items were more difficult than non-occluded items fits with Collins and Kimura's (1997) proposal that task difficulty influences gender differences in performance. As the magnitude of the gender difference in performance was similar across distractor types, Voyer and Hou did not find support for the hypothesis that gender differences would be reduced on structural items compared to mirror items. Voyer and Hou made note of the fact that the Peters et al. (1995) MRT does not contain an equal number of each item type, making variability a possible issue in their study.

Although the results of Voyer and Hou's (2006) experiment did not yield a significant difference in performance between mirror image and structural items, Voyer and Doyle (2010) replicated the occlusion findings of Voyer and Hou and also found a significant effect of distractor type, with participants scoring lower on items that included mirror distractors than items that included structural distractors. Bors and Vigneau (2011) also found that mirror items were more difficult to rotate than structural items for both genders as reflected by lower MRT scores on mirror items. Bors and Vigneau also found a gender by distractor type interaction, with a greater magnitude of gender differences in accuracy on the mirror items than structural items, and replicated Voyer and Hou's occlusion findings. The influence of distractor type suggests a possible link between gender and strategy selection as a function of item types on the MRT. Specifically, in view of the finding that more women than men use an analytic approach as opposed to a holistic approach to mental rotation (e.g., Geiser, Lehmann, & Eid, 2009), such an analytic strategy might be sufficient to rotate structural distractors successfully but it is not an efficient strategy to rotate mirror distractors. Bors and Vigneau (2011) administered the MRT with a 10 minute time limit which, as Voyer and Hou pointed out, affects the number of items completed by each gender and the variance across test items as not all item types are completed. Therefore, Bors and Vigneau's results should be interpreted with caution.

Item Familiarity. The familiarity of items presented during mental rotation tasks also influences gender differences in cognitive strategies and mental rotation performance. Although Shepard and Metzler (1971) provided evidence that mental rotation of cube figures is an analog process as participants take longer to mentally rotate stimuli when the angle of rotation requires that they rotate the item a longer mental distance, Mumaw, Pellegrino, Kail, and Carter (1984) argued that the familiarity of the item to be rotated may affect mental rotation strategies. Mumaw et al. found that participants rotated familiar alphanumeric figures more quickly than unfamiliar items from the Primary Mental Abilities test. The authors suggested that rotating unfamiliar items required stimulus fractionation, that is, focusing on specific pieces or parts of the stimulus, resulting in numerous attempts to mentally rotate the stimuli as the participant tried to keep the internal representation of the stimuli stable. Mumaw et al. also noted that high-ability individuals were faster and more accurate at rotating the unfamiliar stimuli, suggesting that high-ability individuals may be better able to create an accurate mental representation of the unfamiliar stimuli and maintain the quality of these representations during mental rotation.

Bethell-Fox and Shepard (1988) also found a relationship between mental rotation performance and item familiarity. The authors investigated mental rotation of simple, intermediate and complex matrices of quilt-like patterns. Initially, simple matrices were rotated the fastest, complex matrices were rotated the slowest, and RTs for the intermediate matrices fell between these two because, as the authors presumed, item complexity affects encoding and comparison of unfamiliar items. Bethell-Fox and Shepard noted that after participants practiced mentally rotating the matrices, the matrices likely became more familiar and the effect of item complexity on RTs was nullified. Bethell-Fox and Shepard believed this was due to participants improved ability to rotate the matrices holistically once they became familiar with the task. The authors also asked participants to report their strategy when rotating the matrices and found that the two (out of eight) participants who reported using verbal as opposed to analog, visual strategies did not experience the same reduction in the effect of matrix complexity with familiarity. Related to Bethell-Fox and Shepard's findings, Sharps et al. (1994) had male and female participants mentally rotate simple, familiar items and more complex, unfamiliar items. Sharps et al. found gender differences in mental rotation performance on complex, unfamiliar items, but no gender differences in mental rotation performance of simple, familiar items.

Neuburger, Jansen, Heil, and Quaiser-Pohl (2011) extended the study of the effect of item familiarity on gender differences in mental rotation performance to include pre-adolescent children. Neuburger et al. found that fourth grade boys performed better than second grade boys on both familiar items (animals, letters), and unfamiliar items (cubes), yet fourth grade girls outperformed second grade girls only when rotating the familiar items. The authors suggested that the stability of girls' mental rotation ability with unfamiliar stimuli may reflect gender differences in the development of a general mental rotation mechanism.

Embodied Cognition, Item Types, and Strategies

One could argue that there are few things in life as familiar to an individual as their own body, both in its physical makeup and its place in space. One could also argue that the human body is almost always considered one whole object; we generally consider the body to be one unit as opposed to a complex combination of separate body parts. It is because individuals seem to have a special connection with their body and its orientation in the environment that cognitive researchers began to consider the influence of the human body on thought processes (including mental rotation), and began developing theories related to *embodied cognition*.

Embodied Cognition

Embodied cognition involves using one's own sensorimotor experiences as a reference with which to interact and understand one's environment (Wilson, 2002). The field of embodied cognitive science encompasses many research areas, ranging from neuroscience to linguistics, which come together to help provide an understanding of the ways that our body shapes our thoughts (Rohrer, 2007). Anderson (2003, p. 126) explained that embodied cognition aims to understand "the myriad of ways in which cognition depends upon—is grounded in—the physical characteristics, inherited abilities, practical activity, and environment of thinking agents" and that human cognition "exploits repeated interaction with the environment, not only using the world as its own best model, but creating structures which advance and simplify cognitive tasks". Cooper and Shepard (1975) provided valuable insights into the effect of embodied cognition on mental rotation by examining how participants mentally rotate images of hands. Cooper and Shepard had participants make speeded judgments concerning whether a 2D drawing, with either the palm or the back of the hand showing, depicted a left hand or a right hand. Additionally, these 2D hand drawings were rotated in the picture plane at various angles. On some trials, participants were given advance information regarding the orientation of the upcoming hand drawing and were told which hand would be presented, whereas on other trials no advance information was given. When participants were given advanced information regarding which hand would be presented and at what orientation, their performance was fast and error-free, regardless of the designated orientation. This finding suggests that responses were based on what Cooper and Shepard described as a holistic comparison between an internally prepared representation and the external stimulus presented. Essentially, participants might have been using embodied cognition, which encouraged the use of a holistic mental rotation strategy. When the advance information was either incomplete or incorrect, RTs were between 200 and 700 ms slower as participants had to take time to determine the relation between the test hand drawing and an imagined hand. This finding provides further evidence that, to determine which hand drawing was depicted (left or right), participants had to imagine a corresponding hand and then rotate that imagined hand to see if it matched the presented drawing.

Further evidence that participants use embodied cognition to rotate images of hands came from Cooper and Shepard's (1975) finding that participants found it easiest to identify whether hands close to 0° (with fingers pointing up) were left or right hands, and participants had most difficulty identifying whether hands close to 180° (fingers pointing down) were left or right hands. This makes intuitive sense as people most often view their own hands with their fingers pointing upward, and it is easy to rotate their hands to varying degrees from this 0° point. Participants found it more difficult to engage in embodied cognition as they presumably tried to imagine their own hands rotated at 180° with their fingers pointing downwards, and participants in this study did indeed note that there was a kinesthetic component to the task. Therefore, it is likely that their increased RTs at 180° was due to the fact that it is physically awkward to position one's own hand in that inverted orientation.

Following Cooper and Shepard's (1975) initial hand studies, Parsons (1987) found further support for the use of embodied cognition when rotating hands, as participants in his study reported imagining moving their own hand to the orientation of the stimulus as opposed to rotating a stimulus to a standard orientation, the method typically used when rotating letters or numbers. Participants performed fastest when distinguishing if a hand drawing was a left of right hand when the back of the hand was presented with the fingers pointing upward (the 0° mark). Parsons noted that, similar to Cooper and Shepard's findings, making a left or right distinction when hands were presented in this fashion was almost automatic as this is how people typically view their own hands. In a series of follow-up experiments, Parsons (1987) found that when drawings of hands were rotated in depth, and when rotating drawings of feet, participants' "awkwardness ratings" for each body position and actual joint limitations in the body correlated with the amount of time it took to rotate the image and distinguishing whether left or right extremities were presented. Parsons concluded that most RTs from his experiments corresponded to how difficult it is to actually move one's own extremities to match the extremities presented, suggesting participants imagine rotating their own body when mentally rotating images of the body.

Embodied Cognition and Gender Differences in Mental Rotation

Recently, embodied cognition has been added to the list of factors relevant to gender differences in spatial abilities. According to Wilson (2002) many cognitive science researchers have been considering human cognition less in terms of abstract problem solving, and more in terms of embodied cognition; that is, cognition as a necessary process that develops to control the function of our biological bodies within the real world. Wilson proposed that off-line cognition is body-based and is of primary importance to mental rotation abilities. This view suggests that mental structures that were originally evolved for perception or action may be separated from that initial purpose and run out of context (that is, off-line) to aid in thinking and knowing. Wilson asserted that, to assist in thinking, many centralized, abstract cognitive processes off-load by making use of sensorimotor functions, such as using one's knowledge of the look and feel of their hands to assist in mentally rotating images of hands.

It is plausible to argue that mental rotation provides an excellent example of embodied cognition and off-loading occurs when an object is "imitable". Specifically, to make mental rotations easier, one can call on the sensorimotor system and imagine that a block figure to be rotated is analogous to rotating a human body (Amorim et al., 2006). It is also plausible to expect that the ability to engage embodied cognitions during spatial tasks could result in a shift in cognitive strategies and processes. If one can imagine that an abstract figure, such as a block figure, is one whole entity like a human body, it should be easier to mentally rotate that whole entity as one piece (i.e., holistically) than an abstract figure that is imagined in various separate pieces (i.e., analytically or piecemeal). A better understanding of cognition, and cognitive processes within the context of embodied cognition could help shed some light on the causes of gender differences in mental rotation.

Studies examining the effect of item types on mental rotation have provided evidence that this factor affects the magnitude of gender differences in mental rotation performance (e.g., Alexander, & Evardone, 2008; Voyer, & Hou, 2006). When put in context, these studies provide a starting point to clarify the role of embodied cognition and cognitive strategies in explaining gender differences in mental rotation performance.

In comparison to block figures, it has been found that both men and women use a more holistic process when rotating human figures (e.g. Sack, Lindner, & Linden, 2007).

In an extensive study of embodied cognition in mental rotation, Amorim et al. (2006) conducted six mental rotation experiments using 3D figures, including blocks, desk lamps, and human figures (see Figure 1d on page 122 for an example of human figure and desk lamp items). They observed that, when rotating human figures that are analogous to Shepard and Metzler's (1971) block figures, embodiment improved mental rotation performance, especially when the figures were posed in positions that are humanly possible to replicate as opposed to contortions that are not humanly possible to replicate. Embodiment did not contribute to the mental rotation of non-human stimuli, as performance did not improve when rotating desk lamps that were analogous to Shepard and Metzler's block figures. Amorim et al. noted that embodiment appears to rely on more than the simple top-end, bottom-end cues provided by non-block stimuli as the desk lamps clearly had a bulb top and a stand bottom. Participants seemed to have the ability to engage cognitive motoric processes during embodiment, and the ability to use holistic processing more effectively when the figure to be rotated was easily embodied, such as a human figure or a block figure with a human head.

Alexander and Evardone (2008) further examined gender differences in performance on a mental rotations task that involved mentally rotating 3D human figures and block figures. Alexander and Evardone had 99 men and 129 women complete their modified MRT, that consisted of 12 original Peters et al. (1995) block items and 12 novel human figure items (see Figure 1c on page 122 for an example of human figures). In comparison to gender differences found when the Peters et al. MRT was used, the magnitude of gender differences diminished by approximately half when participants mentally rotated the novel 3D human figures, although it remained significant regardless of stimulus type. The authors considered social and hormonal factors as possible sources of these diminished gender differences, yet specific causes remained unclear. It is plausible that the study conducted by Alexander and Evardone (2008) was confounded as the 12 human figures were not structurally equivalent to the 12 block figures from the Peters et al. (1995) MRT. For example, occlusion only appears in three of Alexander and Evardone's human figure items, as opposed to seven of the 24 items on the Peters et al. MRT. Also, the occlusion in one of these items is questionable as it is the head of the figure that is occluded and the comparable original MRT items do not have such identifying features. Basically, Alexander and Evardone's block and human items may have been mismatched in difficulty level; therefore, performance on the block figures and human figures used in their study cannot be considered comparable.

It has been established that mental rotation performance is influenced by the type of stimuli rotated, including variations in item familiarity (e.g., Alexander, & Evardone, 2008; Amorim et al., 2006; Heil, & Jansen-Osmann, 2008), and the magnitude of gender differences in mental rotation may be reduced when human figures are rotated (Alexander, & Evardone, 2008). Sack, Lindner, and Linden (2007) also found that item type affected mental rotation, providing evidence that embodied cognition may influence cognitive strategies used. Sack et al. asked participants to mentally rotate abstract cube figures, hands, and other objects (e.g., carrots, tools) while manually rotating a wheel in either concordant or disconcordant directions. Results indicated that the interference between manual and mental rotation was influenced by the type of stimuli being mentally rotated, with mental rotation of abstract cubes affected by both concordant and disconcordant manual rotation, whereas mental rotation of hands was affected only by disconcordant manual rotations. This interference effect was independent of task difficulty.

Sack et al. (2007) noted that different stimuli might induce different mental rotation strategies, with participants engaging more object-based spatial transformations when rotating cubes, and egocentric perspective transformations when rotating hands. Sack et al. also proposed that concordant manual rotation may be less disruptive when rotating hands as neurons in the primary motor cortex are involved in both the manual rotation of the participant's actual hand and the mental rotation of the hand figure presented. This explanation fits well with Zacks (2008) meta-analysis of neuroimaging studies of mental rotation. Zacks found that brain regions consistently activated during mental rotation tasks included the superior parietal cortex, known to implement spatial maps, and the supplementary motor area, likely reflecting motor simulation. The activation of these brain areas provides evidence that mental rotation involves a continuous, spatial analog process that encourages, to some degree, imagining physically moving the stimuli presented. Zacks also noted that activity in parts of the precentral sulcus was greatest during mental rotation tasks when a motor simulation strategy was engaged, such as tasks that involve mentally rotating images of hands, or tasks that require participants to imagine manually rotating a block figure with their hands. Therefore, there is evidence that motor processes can interact with visuospatial processes, and mental rotation can involve a spatial analog rotation and motor simulations, depending on the types of items presented.

Wraga, Thompson, Alpert, and Kosslyn (2003) used PET scans to examine the possibility that motor strategies can be implicitly transferred when mentally rotating different types of stimuli, from stimuli that require egocentric transformations to stimuli that do not. Wraga et al. had participants mentally rotate either two consecutive sets of Shepard and Metzler (1971) blocks or one set of hand images followed by one set of Shepard and Metzler blocks. Participants were given no instructions to relate either hand stimuli or block stimuli to their own hands. When rotating block stimuli after hand stimuli, PET scans showed more regional cerebral blood flow in the left junction between the premotor area and the primary motor cortex, bilateral activation in the premotor area, and left activation in the insula, believed to be involved in the representation of egocentric space. Further, when blocks were rotated after hand images, several processing areas relevant to visual and spatial working memory were activated. Essentially, the block rotating task that took place after first rotating hand stimuli lead to more "hand"-like neural activity, providing evidence that motor strategies engaged during the rotation of hand stimuli can in fact be implicitly transferred to other stimuli, namely blocks. Wraga et al.'s study included only right-handed male students, and therefore their results cannot confidently be generalized to left-handed individuals or females.

In a related study, Seurinck, Vingerhoets, Lange, and Achten (2004) examined gender differences in brain activation while hands and tools were mentally rotated. In this study, all participants reported using an egocentric strategy to mentally rotate both the tools and the hands, imagining physically grasping and moving the tools or physically moving their own hand to align with the stimuli. In addition, fMRI data showed a common cortical activation pattern for both men and women when they rotated both tools and hands, including activation of the superior parietal lobe, middle frontal gyrus, and extrastriate occipital areas. Subtle gender differences in brain activation were revealed in just two areas during egocentric, or what could also be considered embodied, mental rotation. The authors suggested that women may rely more on imitation or use more perceptual comparisons as they engaged the left ventral premotor cortex, whereas men appear to engage in early visual or semantic processing as they engage their lingual gyrus. The relative absence of gender differences in brain activation compared to gender differences found when men and women rotated blocks (Hugdahl et al., 2006; Jordan et al., 2002) may be the result of reduced gender differences in mental rotation strategy when rotating stimuli that encourage embodied cognition (e.g., hands, tools) compared to stimuli that do not encourage embodied cognition (e.g., abstract block shapes).

Although the role of embodied cognition in mental rotation performance is well established, the possibility that embodied cognition reduces gender differences in mental rotation performance warrants further investigation. If embodied cognition can help individuals to engage in more holistic processing, and, in turn, improve their mental rotation abilities, perhaps spatial training programs should focus on training individuals to use holistic processing with all stimuli, not just stimuli that intuitively leads to embodied cognition (e.g., human figures, animals, furniture). Researchers first need to improve upon the flawed methodology of previous studies investigating embodied cognition and gender differences in mental rotation (e.g., Alexander, & Evardone, 2008) to determine whether there is, in fact, an advantage when rotating human figures compared to block figures with otherwise equivalent tasks. If such an advantage exists, it will be legitimate to proceed with an empirical exploration of why this advantage exists and how it affects gender differences in mental rotation.

CHAPTER II

Goals of the Present Research

The goal of the two articles included in this dissertation was to gain a better understanding of the effect of embodied cognition and holistic processing on gender differences in mental rotation. Article I aimed to improve upon Alexander and Evardone's (2008) methodology to investigate the role of embodiment and holistic processing in explaining gender differences in mental rotation. Mainly, the study was developed to answer the following research questions: (1) If human figures are directly analogous to block figures, will Alexander and Evardone's (2008) results be replicated, with participants performing better when rotating the human figures than when rotating the block figures?; (2) Again attempting to replicate Alexander and Evardone, will the gender difference in mental rotation performance be reduced when rotating these human figures compared to the gender difference when rotating analogous block figures?; (3) If embodied cognition encourages the use of holistic processing, will it help participants to think of the parts of an item as a whole thereby reducing the effect of occlusion when rotating human figures compared to the effect of occlusion when rotating block figures?; and, (4) If men already engage in holistic processing when rotating block and human figures, will rotating human figures encourage embodied cognition among females and subsequently reduce the magnitude of the effect of occlusion among women compared to men?

To better understand the role of embodied cognition on mental rotation processes in Article I, Doyle and Voyer (2013) created a novel block MRT (MRT-R), and a novel human figure MRT (MRT-B). The MRT- R consisted of an equal numbers of occluded, non-occluded, structural and mirror block items, and the MRT-B was developed using human figures directly analogous to the block figures. Creating tests with equal numbers of each item type was expected to reduce the large amount of variability in accuracy seen in Voyer and Hou (2006) (for example, see Table 1 of their paper). In addition, unlike Alexander and Evardone's (2008) study, the computer generated human figures created for the MRT-B were bent at the waist, knees, hips and ankles to make the figures as analogous to the block items on the MRT-R as possible.

Contrary to the results reported by Alexander and Evardone (2008), in Article I Doyle and Voyer (2013) found that both men and women performed less accurately when rotating the human figures on the MRT-B than when rotating the block figures on the MRT-R. We suggested that this result may be due to the fact that the human figures on the MRT-B were more complex than the block figures on the MRT-R. It seems that complexity of an object, like the desk lamps mentioned earlier, has a greater effect on mental rotation performance than familiarity of the object being rotated (Amorim et al., 2006; Heil, & Jansen-Osmann, 2008b). In addition, the computer drawn human figures developed for the MRT-B were not always positioned in humanly possible postures. Doyle and Voyer (2013) also found that the effect of occlusion on women's MRT performance was reduced on the MRT-B. This reduction in the effect of occlusion on women's performance may be the result of embodied cognition. Women may be using a more holistic approach when rotating human figures compared to block figures, therefore reducing the deleterious effect of occlusion on their performance. The effect of occlusion on men's MRT performance remained the same across both the MRT-R and the MRT-B, as men presumably used a holistic approach regardless of the stimuli presented.

Article II aimed to further explore participants' decreased accuracy when rotating human figures on the MRT-B compared with the MRT-R. In addition, Article II further considered the role of image familiarity, embodied cognition and strategy on gender differences in performance on the MRT-R and the MRT-B and aimed to answer the question: If the human figures are clearly more realistic (familiar), will participants be able to better engage embodied cognition (holistic processing) and improve their mental rotation scores compared to performance on analogous block figures? As discussed earlier, Cooper and Shepard (1975), and Parsons (1987) have shown that when body parts that are difficult to replicate with one's own body are presented, they are more difficult to rotate than when body parts are presented in anatomically correct, comfortable, and common positions. It appears that it is easier to engage in embodied cognition when the stimuli closely approximate the capabilities of one's own body. Therefore, participants in Doyle and Voyer (2013) may have had difficulty engaging embodied cognition and mentally rotating images from the MRT-B as the human figures were created by bending the shoulders, waists, hips, knees, and ankles at 90° angles. This often led to the creation of human figures that, while closely resembling the block figures presented on the MRT-R, were positioned in contortions that were not humanly possible. Therefore, important questions remain to be answered: (1) Would the gender difference in mental rotation be reduced if participants were rotating clearly realistic human figures?; (2) Would embodied cognition (holistic processing strategies) be more readily engaged?; and, (3)Would the effect of occlusion be reduced to a greater extent when rotating realistic human figures than when rotating analogous block figures, as compared to the reduced effect of occlusion when rotating computer drawn human figures (presumably reflecting an increased propensity to engage holistic processing)?

To address these outstanding questions, I created a new MRT, using real human figures produced by photographing real human models positioned as closely as possible to the computer drawn figures from MRT-B. I hypothesized that these realistic, anatomically correct human figures would encourage embodied cognition and holistic processing more so than the MRT-B items, and when compared to analogous block figures, these real human figures would lead to improved mental rotation performance among both men and women, reduced magnitude of gender differences in mental rotation, and reduced effect of occlusion on women's performance when compared to analogous block figures.

CHAPTER III

Article I: Bodies and occlusion: Item types, cognitive strategies, and gender differences in mental rotation

Doyle, R. A., & Voyer, D. (2013). Bodies and occlusion: Item types, cognitive strategies, and gender differences in mental rotation. *Quarterly Journal of Experimental Psychology, 66,* 801-815. doi:10.1080/17470218.2012.719529

Formatted as required by the Quarterly Journal of Experimental Psychology.

Abstract

The aim of the current study was to re-examine previous findings in which the magnitude of the male advantage in mental rotation abilities increased when participants mentally rotated occluded versus non-occluded items, and decreased when participants mentally rotated human figures versus blocks. Mainly, the study aimed to address methodological issues noted on previous human figure mental rotations tests as the items composed of blocks and human body were likely not equivalent in terms of their cognitive requirements. Results did not support previous research on embodied cognition as mental rotation performance decreased among both men and women when mentally rotating human figures compared to block items. However, for women, the effect of occlusion was decreased when mentally rotating human figures. Results are discussed in terms of task difficulty and gender differences in confidence and guessing behavior.

Bodies and Occlusion:

Item Types, Cognitive Processes, and Gender Differences in Mental Rotation

It has been well established that on average, men perform better than women on tasks that engage spatial abilities (Linn & Petersen, 1985; Voyer, Voyer & Bryden, 1995). In addition, the Mental Rotations Test (MRT; Vandenberg & Kuse, 1978), a test of mental rotation ability using three-dimensional stimuli, tends to produce the largest of these gender differences in spatial ability (Voyer et. al, 1995). The mental rotation task was originally developed by Shepard and Metzler (1971) to determine whether participants' response times were a function of the angular difference between the images when determining if a pair of three-dimensional block images were the same or different. Vandenberg and Kuse (1978) later used the three-dimensional block images from the mental rotations task (Shepard & Metzler, 1971) in order to develop a pen-and-paper version of the mental rotation task, which they called the Mental Rotations Test (MRT). Following the deterioration of the Vandenberg and Kuse MRT, Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) revised the original pen-and-paper test using a computer-assisted drawing program and this is the version of the test that most researchers use nowadays.

The implications of gender differences in mental rotation are widespread. Most notably, performance on spatial tests has been correlated with mathematics achievement (Casey, Nuttall & Pezaris, 2001; Rosselli, Ardila, Matute & Inozemtseva, 2009). In addition, gender differences in spatial abilities are related to performance on high stakes standardized tests, such as the Scholastic Aptitude Test (SAT; Bridgeman & Wendler, 1991; Casey, Nuttall, Pezaris & Benbow, 1995). There appear to be numerous factors related to gender differences in spatial ability, including sex hormones (Berenbaum, Korman & Leveroni, 1995), experience with childhood spatial activities (Serbin & Connor, 1979; Voyer, Nolan & Voyer, 2000; Cherney, 2008, Cherney & Voyer, 2010), gender role identity (Signorella & Jamison, 1978; McGlone & Aronson, 2006) and even the confidence one has in their own spatial abilities (Cooke-Simpson & Voyer, 2007).

Recently, embodied cognition (Lakoff & Johnson, 1999) has been added to the list of factors of relevance to gender differences in spatial abilities. In fact, according to Wilson (2002) many researchers in the field of cognitive science have been considering human cognition less in terms of abstract problem solving, and more in terms of embodied cognition; that is, cognition as a necessary process that develops in order to control the function of our biological bodies within the real world. Wilson went on to outline six views of embodied cognition present in the literature. The sixth view outlined by Wilson, that off-line cognition is body-based, is of primary importance to mental rotation abilities. This view suggests that mental structures that were originally evolved for perception or action may be separated from that initial purpose and run out of context (that is, off-line) in order to aid in thinking and knowing. Wilson essentially asserted that, to assist in thinking, many centralized, abstract cognitive processes off-load by making use of sensorimotor functions.

Mental rotation provides an excellent example of embodied cognition and off-loading when an object is "imitable". Specifically, to make mental rotations easier, one can call on their sensorimotor system and imagine that a block image to be rotated is analogous to a human body being rotated (Amorim, Isableu & Jarraya, 2006). It is easy to imagine that the ability to engage embodied cognitions during spatial tasks could result in a shift in cognitive process. If one can imagine that an abstract image, such as a block figure, is one whole entity like a human body, it should be easier to mentally rotate that whole entity as one piece (i.e., holistically) than an abstract image that is imagined in various separate pieces (i.e., piecemeal). A better understanding of cognition, and cognitive processes within the context of embodied cognition, could help shed some light on the causes of gender differences in mental rotation.

Recent studies have revealed that the type of mental rotation items considered affects the magnitude of gender differences (Voyer & Hou, 2006; Alexander & Evardone, 2008). When put in context, these studies provide a starting point to clarify the role of embodiment and cognitive strategies in explaining gender differences in mental rotation performance. Specifically, Voyer and Hou (2006) examined the effect of occlusion (defined as images rotated in such a way that parts of the object are not visible) on the magnitude of gender differences on the MRT. Voyer and Hou (2006) found that the male advantage was larger for occluded than non-occluded items. In a related item-type study, Voyer and Doyle (2010) found evidence that women are more reluctant to guess on occluded than non-occluded items. As occlusion reflects depth, these findings allude to the three-dimensional nature of the MRT playing an important role in item difficulty and the resulting magnitude of gender differences.

Using a different approach to item type manipulation, Alexander and Evardone (2008) examined gender differences in performance on a mental rotations task that involved mentally rotating three-dimensional human figures as opposed to block images. In comparison to gender differences on the Vandenberg and Kuse (1978) MRT, the magnitude of gender differences diminished by approximately half when participants mentally rotated three-dimensional human figures. Although the authors considered social and hormonal factors as possible sources of these diminished gender differences, specific causes remained unclear. However, it is plausible to argue that the study conducted by Alexander and Evardone (2008) was confounded as the human figures they used were not structurally equivalent to the block images on the MRT. For example, occlusion only appears in three of Alexander and Evardone's human figure questions and the occlusion in one of these items is questionable as it is the head of the figure that is occluded and the comparable original MRT items do not have such identifying features. Essentially, Alexander and Evardone's block and human items may have been mismatched in difficulty level; therefore, performance on the block images and human figures used in their study cannot be considered comparable.

Gender differences have also been observed in the cognitive strategies used during mental rotation, with men using more of a holistic process when mentally rotating images in that they tend to synthesize visual information, imagine figures as a whole, and rotate the entire image (Alexander & Son, 2007; Jordan, Wüstenberg, Heinze, Peters, & Jäncke, 2002). In contrast, women are presumed to use more of an analytic process. Specifically, they tend to consider the individual parts or features of an image and attempt to rotate the resulting piecemeal mental image (Alexander & Son, 2007; Jordan et al., 2002). Heil and Jansen-Osmann (2008) found that women's mental rotation speed decreased as the complexity of polygons increased whereas men's mental rotation speed was not affected by polygon complexity. The authors concluded from this finding that men are more likely to use a holistic mental rotation process whereas women are more likely to use an analytic, "piecemeal" mental rotation process. Gender differences in brain activation during mental rotation also point to the possibility that men and women utilize different cognitive strategies, with men using a more "hands on" approach to mental rotations, engaging the primary motor cortex in order to imagine physically moving the items, and women using a more piecemeal process when mentally rotating items as the inferior temporal gyrus is involved in object-part identification (Jordan et al., 2002).

It is also noteworthy that, in comparison to block figures, both men and women have been found to use a more holistic process when rotating human figures. In a series of experiments Amorim, Isableu, & Jarraya (2006) observed that, when rotating human figures that are analogous to Shepard and Metzler's (1971) block images, the facilitation of embodiment improved mental rotation performance. Embodiment did not to facilitate the mental rotation of non-human stimuli, as performance did not improve when rotating desk lamps analogous to Shepard and Metzler's block images. The authors noted that embodiment appears to rely on more than the simple top-end, bottom-end cues provided by non-block stimuli as the desk lamps clearly had a bulb top and a stand bottom. Participants seemed to have the ability to engage cognitive motoric processes during embodiment, and the ability to use holistic processing more effectively when the figure to be rotated was easily embodied, such as a human figure or a block figure with a human head.

The current study aimed to improve upon Alexander and Evardone's (2008) methodology in order to investigate the role of embodiment and cognitive processes in explaining gender differences in mental rotation. Two novel versions of the Peters et al. (1995) re-drawn MRT were developed in order to conduct the experiment. One of these novel MRTs consisted of an equal numbers of occluded, non-occluded, structural and mirror block items, and the other was a directly analogous version of this revised MRT developed using human figures as opposed to blocks. The original Peters et al. (1995) MRT items included some occluded items (as defined earlier) as well as items in which the incorrect responses (distractors) were either a mirror image of the target or structurally different from the target. However, the number of each of these items was unequal. For example, the original test comprised only two structural-occluded items. Creating tests with equal numbers of each item type was expected to reduce the large amount of variability in accuracy seen in the Voyer and Hou (2006) study (for example, see Table 1 of their paper). Four main hypotheses guided the current study:

H1: It was hypothesized that gender differences in performance on the novel versions of the MRT would replicate gender differences in performance on the original MRT with men completing both novel versions of the MRT more accurately than women.

H2: It was hypothesized that Voyer and Hou's (2006) original MRT item-type findings would be replicated, with both men and women performing more accurately on non-occluded than occluded items, with a larger male advantage for occluded than non-occluded items.

H3: As the use of a holistic process appears to improve performance in spatial abilities (Heil & Jansen-Osmann, 2008), it was hypothesized that the effect of occlusion when mentally rotating human figures would be decreased for both men and women.

H4: It was hypothesized that the magnitude of this decrease in the effect of occlusion would be more pronounced for women as their improved performance when mentally rotating human figures would stem from a switch to a holistic process, whereas men likely use this process for both block and human figures.

Method

Participants

One hundred and seventy nine students (82 males, 97 females, mean age = 20.07, SD = 3.55) were recruited from Introductory Psychology classes at the University of New Brunswick using a web-based booking program. Participants were predominantly Caucasian (62%) and right handed (88%). They received one point towards their Introductory Psychology grade. Participation was voluntary and all participants signed a consent form before starting the experiment. This study was approved by the institutional Research Ethics Board.

Materials

Demographics

The first page of the test booklet consisted of a brief demographics questionnaire. This questionnaire required participants to indicate their age, gender (male or female), and ethnic background.

Revised MRT

A bank of block images provided by Michael Peters (Peters & Battista, 2008) was used to select figures meeting the specific criteria (relevant to occlusion, structure, etc.) required to build the revised test items. Items chosen were modified using a computer assisted drawing program to remove shading in the original figures. Like the Peters et al. (1995) MRT, this revised MRT (MRT-R hereafter) includes instructions on its cover page, followed by four practice questions, and 24 test items.

For each test item, participants are required to examine a target block image on the left and choose the two block images that are the same as the target image but rotated in space among an array of four response alternatives (two correct alternatives and two distractors) on the right of the target. Because axis of rotation can affect mental rotation performance (Parsons, 1987a; Parsons, 1987b), all correct alternatives on the MRT-R and Bodies MRT (described below) were rotated around a vertical axis. Distractor items may consist of block images that are mirror images of the target or block images that are structurally different from the target image. In addition, items on the MRT may include response alternatives that are occluded (rotated such that parts of the block image are not visible) or non-occluded (rotated such that all parts of the block image is visible). The MRT-R was constructed in such a way that it was divided into six blocks of four items with each item type combination (structural occluded, structural non-occluded, mirror occluded, mirror non-occluded) represented once in each block, resulting in six items of each type in the full test. Item type combinations were randomly ordered in each of the six blocks. For an example of mirror occluded and structural non-occluded items, see Figure 1. As in the original MRT, identifying both correct response alternatives on the MRT-R resulted in one point whereas any other response resulted in no point, with a maximum possible score of 24. This measure demonstrated high internal consistency in the present sample (α = .92).

Bodies MRT

The Bodies MRT (MRT-B hereafter) was developed to replicate the block images on the MRT-R but using human figures. These human figures were created with Poser 8 (Smith Micro Software Inc., 2009), a three-dimensional character art and animation computer program. With their arms and legs held together, the human figures were formed by bending the three-dimensional bodies at 90º angles from the shoulders, torso, knees and ankles in order to replicate the 90º bends in the various block images on the MRT-R. Bending the human figures in such a way resulted in some potentially unrealistic human figures. Accordingly, the two authors rated the human figures as either realistic or unrealistic, based on whether it was possible to contort their actual body to match the MRT human figures. Initial ratings resulted in 87.5% inter-rater reliability. Items that resulted in disagreements were discussed until 100% inter-rater agreement was reached. This realism variable, resulting in 9 items rated as realistic and 15 rated as unrealistic, was used in the preliminary analyses to investigate its potential effect on the results.

The head of each body was held downward between outstretched arms with the chin against the chest as the block images on the MRT-R do not have any identifying peaks like a head. Twelve male and 12 female human figures were counterbalanced throughout the test. Although female figures had shoulder length hair, the color and style of dress was as similar as possible, with both males and females wearing the same plain slacks and t-shirts. After their initial creation in Poser, all images were edited using the online photo editing site Picnik.com (Sposato, Massena & Harrington, 2007). This editing involved conversion of the figures from color to black and white. Next, the figures were converted to pencil sketches with radius set at 1.3, strength at 200%, and fade at 25%. The color and effect of the Poser figures was changed in order to make the human figures more closely resemble the blocks on the Peters et al. (1995) MRT and the MRT-R, but preserving the internal structure of the bodies, similar to lines delineating blocks in the MRT and MRT-R. The instructions, practice questions and 24 items on the MRT-B were the same as on the MRT-R except for the fact that each block item was replaced with an analogous male or female human figure. Therefore, like the MRT-R, the MRT-B consisted of six mirror occluded items, six mirror non-occluded items, six structural occluded items, and six structural non-occluded items randomized within blocks of four items. For an example of mirror occluded and structural non-occluded human figures, see Figure 1. Identifying both correct response alternatives on the MRT-B results in one point whereas any other response results in no point. The maximum possible score is, again, 24. This test also demonstrated high internal consistency in the present sample ($\alpha = .87$).

(Figure 1 about here)

Procedure

Participants were tested in a room specially designed for small group testing. All participants were tested in the same room with a maximum of four participants per testing session. Each participant was seated at a desk flanked by dividers. Two different versions of the test booklet were administered; each began with a demographics questionnaire but the MRT-R and the MRT-B were presented in a counterbalanced order. After signing a consent form, participants received their test booklet and were asked to complete only the demographics questionnaire. When all participants had completed the demographics questionnaire, the experimenter read the instructions for the MRT aloud, giving participants time to complete the practice questions. Participants were instructed to put their pen down after completing the first MRT in their booklet. When all participants had completed the first MRT, the experimenter read the directions of the second MRT aloud, again giving participants time to complete the practice questions. Upon completion of the second MRT, the experimenter concluded the experiment by distributing a debriefing sheet to each participant. Following the approach used by Voyer and Hou (2006), both the MRT-R and the MRT-B were administered without time limits so that participants could complete all test items.

Results

Preliminary Analysis

Preliminary analyses evaluated the possible influence of variables unrelated to the hypotheses, such as the gender of the human figures on the MRT-B, and the realism of the human figures. For each significant interaction obtained in ANOVA, simple main effects were analyzed based on the approach recommended by Winer (1962). The .05 level of significance was used for all analyses.

Data were first screened for outliers and none were identified as no participants scored more than 3 standard deviations above or below the mean on MRT-R or MRT-B scores. Levene's test revealed that the assumption of homoscedasticity was violated. Accordingly, data analysis was computed on arcsine transformed variables as recommended by Myers (1972). Under this transformation, the data met the assumptions. However, as most readers might not be familiar with arc-sine transformed values, the data are presented in their untransformed state when means are reported in order to ease interpretation.

Data were then analyzed with a mixed-design ANOVA to determine whether the gender of items on the MRT-B (men figures, women figures) and gender of participants (men, women) affected the mean proportion of correct responses. Alexander and

Evardone's (2008) findings were not replicated. Specifically, although there was a main effect of gender of participants on MRT-B performance, $F(1, 177) = 11.54$, $p < .01$, $\eta^2 = .06$, there was no main effect of gender of figures, $F(1,177) = 1.85$, $p = .18$, $\eta^2 = .01$, and no significant gender of participants by gender of figures interaction, $F(1, 177) = 1.42$, $p = .24$, $\eta^2 = .01$. The main effect of gender reflected better performance in men ($M = .65$, $SD = .24$) than in women ($M = .54$, $SD = .23$). Finally, accuracy on the MRT-R and the MRT-B was significantly correlated, $r = .75$, $p < .01$, therefore, it is likely that the MRT-R and MRT-B are measuring the same construct, as expected.

The effect of the realism of the human figures on performance was also examined by using the proportion of correct responses on the MRT-B as dependent variable in a mixed-design ANOVA with gender of participants (men, women), occlusion (occluded vs. non-occluded), distractor type (mirror vs. structural), and realism (realistic vs. unrealistic) as independent variables. This analysis showed a significant realism by type interaction, $F(1, 177) = 9.74$, $p < .01$, $\eta^2 = .05$. Simple main effect analyses of this interaction showed that the effect of realism was significant on mirror items, $F(1,178) = 9.90$, $p < .01$, $\eta^2 = .05$, with participants completing unrealistic mirror items (M = .54, SD =.31) more accurately than realistic mirror items (M = .47, SD = .34). The effect of realism was not significant on structural items, $F(1,178) = 0.61$, $p = .44$, $\eta^2 = .003$, with similar scores on both realistic structural items (M = .66, SD =.30) and unrealistic structural items (M = .64, SD = .21). However, the effect of realism did not interact with other factors, including gender, $F(1, 177) = 0.75$, $p = .39$, $\eta^2 = .004$, and occlusion, $F(1, 177) = 2.87$, $p = .09$, $\eta^2 = .02$. In addition, the inclusion of a realism factor as a covariate in the primary analysis reported below (operationalized as the difference in performance between realistic and unrealistic items for each participant) did not affect significant results. Accordingly, whether or not items depicted realistic body postures was not considered in further analyses.

Primary Analysis

The hypotheses of the present experiment were tested by means of a mixed-design ANOVA with gender of participants (men, women), test (MRT-R vs. MRT-B), occlusion (occluded vs. non-occluded), and distractor type (mirror vs. structural) as independent variables and the proportion of correct responses on the MRT-R and MRT-B as the dependent variable . Again, simple main effects were analyzed based on the approach recommended by Winer (1962). Effect sizes (Cohen's *d*; Cohen, 1977) were calculated as performance for men minus performance for women divided by the pooled standard deviation in order to interpret results more closely.

Gender Differences

H1: The analysis revealed a main effect of gender, $F(1, 177) = 20.31$, $p < .01$, $\eta^2 = .10$, and a main effect of test, $F(1, 177) = 24.30$, $p < .01$, $\eta^2 = .12$. However, these main effects were qualified by a gender by test interaction, $F(1, 177) = 7.57$, $p < .01$, $\eta^2 = .04$. Simple main effects analysis showed that the effect of gender was significant on both the MRT-R, $F(1,177) = 24.03$, $p < .01$, $\eta^2 = .12$, and the MRT-B, $F(1,177) = 11.54$, $p < .01$, $\eta^2 = .06$. Means relevant to this interaction are presented in Table 1. Considering the significance of gender differences on both MRTs, the magnitude of the *F* tests, and the means and effect sizes presented in Table 1 suggest that the interaction is due to the fact that the male advantage was significantly larger on the MRT-R than on the MRT-B.

H2: A main effect of occlusion, $F(1, 177) = 156.96$, $p < .01$, $\eta^2 = .47$, was qualified by a gender by occlusion interaction, $F(1, 177) = 5.55$, $p < .05$, $\eta^2 = .03$. Simple main effects analysis revealed that a significant male advantage was obtained for both occluded items, $F(1,177) = 21.08$, $p < .01$, $\eta^2 = .11$, and non-occluded items, $F(1,177) = 16.28$, $p < .01$, $\eta^2 = .08$. Means relevant to this interaction are presented in Table 1. Again, the magnitude of the *F* values, and the means and effect sizes in Table 1 suggest that the gender by occlusion interaction can be accounted for by the finding that gender differences were significantly larger on occluded items than on non-occluded items.

(Table 1 about here)

H3: The gender by test interaction and gender by occlusion interaction were further qualified by a gender by test by occlusion interaction $F(1, 177) = 4.35$, $p < .05$, $\eta^2 = .02$. Means relevant to this three-way interaction are presented in Table 2. The first step to simple main effects analyses showed that the gender by occlusion interaction was significant on the MRT-R, $F(1,177) = 11.45$, $p < .01$, $\eta^2 = .06$, but not on the MRT-B, $F(1,177) = 0.08$, $p > .77$. Accordingly, as a second step, the effect of gender on occluded and non-occluded items was examined on the MRT-R only. Gender differences in favour of men were found to be significant on both occluded items, $F(1,177) = 27.59$, $p < .01$, $\eta^2 = .14$, and non-occluded items, $F(1,177) = 15.84$, $p < .01$, $\eta^2 = .08$. As seen in Table 2, once more, the magnitude of the *F* values, and the means and effect sizes support the conclusion that gender differences were significantly larger on occluded items than on non-occluded items, but only on the MRT-R.

H4: In order to refine interpretations, results of the gender by test by occlusion interaction were also examined by considering the effect of occlusion on each test within each gender (as opposed to the effect of gender as a function of occlusion presented above). The first step of analysis revealed that the test by occlusion interaction was significant among women, $F(1, 177) = 14.63$, $p < .01$, $\eta^2 = .08$, but not men, $F(1, 177) = .47$, $p > .48$, $\eta^2 = .003$. As a second step, the effect of occlusion on MRT-R and MRT-B performance was examined among women only. Occlusion had a significant effect on women's performance on both the MRT-R, $F(1,96) = 122.07$, $p < .01$, $\eta^2 = .56$, and on the MRT-B, $F(1,96) = 25.95$, $p < .01$, $\eta^2 = .21$. Although significant on both tests, the magnitude of the *F* values, and the means presented in Table 2 suggest that the significant test by occlusion interaction in women reflects a reduced effect of occlusion on their performance on the MRT-B compared to the MRT-R.

(Table 2 about here)

Distractor Type

The analysis revealed a main effect of distractor type, $F(1, 177) = 148.24$, $p < .01$, $\eta^2 = .46$, which was qualified by a gender by distractor type interaction, $F(1, 177) = 12.26$, $p < .01$, $\eta^2 = .07$. Simple main effects analysis revealed that gender differences in favour of men were significant for both structural distractor items, $F(1,177) = 13.43$, $p < .01$, $\eta^2 = .07$, and mirror distractor items, $F(1,177) = 23.37$, $p < .01$, $\eta^2 = .12$. Means relevant to this interaction are presented in Table 1. In this case, the magnitude of the *F tests*, and the means and effect sizes in Table 1 suggest that the male advantage was significantly larger for mirror distractor items than for structural distractor items.

Occlusion

A distractor type by occlusion interaction was also found $F(1,177) = 60.48$, $p < .01$, $\eta^2 = .26$, as was a test by occlusion interaction $F(1,177) = 9.55$, $p < .01$, $\eta^2 = .05$. These interactions were qualified by a test by distractor type by occlusion interaction $F(1,177) = 5.68$, $p < .05$, $\eta^2 = .02$. Means relevant to this interaction are presented in Table 3.

The first step to simple main effects analyses showed that the distractor type by occlusion interaction was significant on both the MRT-R, $F(1,177) = 15.26$, $p < .01$, $\eta^2 = .08$, and the MRT-B, $F(1,177) = 48.67$, $p < .01$, $\eta^2 = .22$. However, the three-way interaction is clarified as the effect of occlusion was significant for MRT-R mirror distractor items, $F(1,177) = 130.01$, $p < .01$, $\eta^2 = .42$, and MRT-R structural distractor items, $F(1,177) = 43.14$, $p < .01$, $\eta^2 = .20$, but the effect of occlusion was only significant for MRT-B mirror distractor items $F(1,177) = 84.85$, $p < .01$, $\eta^2 = .32$, and not for MRT-B structural distractor items, $F(1,177) = .47$, $p > .48$, $\eta^2 = .003$. No other main effects or interactions achieved significance at the .05 level.

(Table 3 about here)

Discussion

The present study aimed to examine the potential role of embodied cognition in promoting efficient mental rotation in both men and women. It was hypothesized (H1) that gender differences in mental rotation would be replicated with men performing more accurately than women on both the block version of the MRT (MRT-R) and the version of the MRT where items were composed of human bodies (MRT-B). It was also expected (H2) that Voyer and Hou’s (2006) item-type findings would be replicated with participants performing more accurately on non-occluded than occluded items and the magnitude of the gender differences in favour of men would be larger on occluded items. It was also hypothesized (H3) that the use of holistic processing would reduce the magnitude of the effect of occlusion when mentally rotating human figures on the MRT-B, and that this reduced effect of occlusion when rotating human figures would be more pronounced in women (H4). Table 4 presents a summary of findings relevant to significant interactions.

(Table 4 about here)

The first hypothesis, that gender differences in performance on the novel versions of the MRT would replicate gender differences in performance on the original MRT, was supported. Previous research was replicated, with men scoring higher than women on both the MRT-R and the MRT-B (see Table 1). The replication of significant gender differences in favour of men in mental rotation performance (Linn & Petersen, 1985; Voyer et al., 1995) combined with the high internal consistency achieved on both tests suggests that the novel versions of the MRT are valid measures of mental rotation. Additionally, the novel MRT-R and MRT-B were constructed in such a way that they included equal numbers of occluded, non-occluded, structural distractor, and mirror distractor items. Having equal amounts of each item type reduced the variability in accuracy when compared to the Voyer and Hou’s (2006) study. Most notably, the standard deviations of men's and women's scores on occluded items were reduced from .33 and .39 in the Voyer and Hou study to .27 and .31, respectively for each gender, in the present study. As well, the standard deviations of men's and women's scores on structural distractor items were reduced from .26 and .27 in the Voyer and Hou study to .19 and .21, respectively, in the present study.

The second hypothesis, that Voyer and Hou's (2006) occlusion findings would be replicated, was supported as both men and women scored higher on non-occluded than occluded items and the magnitude of gender differences in favour of men were larger on occluded than non-occluded items. This supports the notion that the three-dimensional nature of the stimuli, as implemented by the occlusion of specific parts, is crucial to the large magnitude of gender differences on the MRT, as was proposed by Voyer and Hou (2006).

Interestingly, as predicted (but not obtained) by Voyer and Hou (2006), a significant gender by distractor type interaction was observed in the present experiment, with larger gender differences in favor of men for mirror distractor items than structural distractor items (see Table 1). Voyer, Rodgers and McCormick (2004) proposed that MRT items with structural distractors are easier to complete than items with mirror distractors. These authors suggested that mental rotation is necessary when searching for correct alternatives among mirror distractors whereas other non-rotational strategies, such as object identification, are sufficient when searching for correct alternatives among structural distractors and identifying structurally different item features. Therefore, the finding that gender differences in favor of men are larger for items with mirror distractors supports the notion that men have better mental rotation abilities than women.

It was also found that occlusion had a significant effect on both mirror distractor items and structural distractor items on the MRT-R, yet occlusion had a significant effect on mirror distractor items but not structural distractor items on the MRT-B (see Table 3). This may be due to the approach used in the construction of the structurally different distractors on the MRT-B. The structure of the human body could not be completely different (e.g., we could not add another joint to a human arm), so only the placement of the arms and legs could be manipulated to make the bodies look structurally different from the target while matching the corresponding MRT-R item as closely as possible. Accordingly, to manipulate the human figures such that they would replicate the block figures yet remain realistic, either knees or ankles were bent at 90º to reflect structural differences (see Figure 1). In contrast, the block MRT-R items could be constructed to have what appeared to be a completely different structure. Therefore, it may have been easier for participants to identify MRT-B structural distractors than MRT-B mirror distractors, regardless of occlusion. Structural distractors may not have been as easy to identify when considering block items on the MRT-R as these structurally different items were constructed using different numbers of blocks in the tails of the items. Thus occlusion continued to have a significant effect on participants' performance on both structural and mirror MRT-R items.

It is likely that the effect of distractor type achieved significance on the MRT-R and the MRT-B and not in Voyer and Hou's (2006) study as a result of the inclusion of equal numbers of structural and mirror distractor items on these novel tests. Voyer and Hou administered the Peters et al. (1995) original MRT that includes 10 structural distractor items, 12 mirror distractor items, and 2 mixed distractor items (one mirror and one structural distractor). As previously discussed, smaller standard deviations in the current study compared to standard deviations reported in Voyer and Hou's (2006) study reflect a reduction in variability in the tests developed here. This reduced variability likely increased the probability of rejecting the null hypothesis in the present study (Jackson, 2006).

The third hypothesis, that due to enhanced holistic processing, the effect of occlusion when mentally rotating human figures would be decreased among both men and women, was partially supported. The effect of occlusion on men's performance was not significantly different on the MRT-R and the MRT-B. However, the effect of occlusion on women's performance was significantly reduced on the MRT-B compared to the MRT-R. This finding lends support to the fourth hypothesis, that the decrease in the effect of occlusion on the MRT-B would be more pronounced for women than for men. While the fourth hypothesis was supported and the reduced effect of occlusion on the MRT-B was greater for women, this finding was not due to the mechanisms originally assumed. Holistic processing did not appear to enhance participants performance as both men's and women's mean accuracy decreased on the MRT-B compared to the MRT-R. Although the decreased effect of occlusion on women's MRT-B performance could reflect women using embodied cognition (likely a more holistic process) on occluded MRT-B items, it is perplexing that they did not appear to use this embodied cognition approach on non-occluded MRT-B items as their performance decreased on these items.

Another possible explanation for the decreased effect of occlusion on women's MRT-B performance involves the effect of guessing on performance. Voyer et al. (2004)

found that women were more reluctant to guess than men on Vandenberg and Kuse (1978) MRT items, and this reluctance to guess increased as allotted time for items completion decreased. In the current study, due to their previous knowledge of the human body, women may have had an easier time guessing - and subsequently been more confident to guess - where occluded arms or legs might be located on MRT-B items than guessing where occluded block parts might be located on MRT-R items. In contrast, as men are generally more confident in their mental rotation abilities than are women (Cooke-Simpson & Voyer, 2007) and have a tendency to guess more often than women (Voyer et al., 2004), men's propensity to guess on occluded items would likely be similar on both the MRT-R and the MRT-B.

Because participants typically do not complete all MRT items when they are performing under decreased time limits (Cooke-Simpson & Voyer, 2007; Voyer et al., 2004), the tests were administered without time limits in the present experiment to allow for the comparison of equal numbers of each item type. In order to test whether this absence of time limits affected women's guessing behavior, the MRT-R and MRT-B would need to be administered with time limits. Presumably, performing under time limits, women's responses would reflect an increased propensity to guess on occluded MRT-B items compared to occluded MRT-R items, with more blank responses on occluded MRT-R items. It might also be interesting to have participants rate their confidence in their responses on each MRT-R and MRT-B item to determine whether women's confidence increases on occluded MRT-B items compared to their confidence on occluded MRT-R items.

Clearly, Alexander and Evardone's (2008) finding that mental rotation is improved when rotating human figures was not replicated. This is likely due to the fact that Alexander and Evardone's human figures were not created to match the Peters et al. (1995) MRT items that they replaced, whereas the human figures on the MRT-B were created to replicate the corresponding block items on the MRT-R exactly (or as closely as possible). Therefore, mental rotation performance on Alexander and Evardone's block items and human figures was not directly comparable. In addition, Amorim et al. (2006) found that Shepard and Metzler (1971) cubes with heads attached to them were rotated more easily than regular Shepard and Metzler cubes. This is presumably due to the heads cuing participants as to the up-down axis of the figure. The fact that Alexander and Evardone's (2008) human figures were presented with their heads upright while bodies on the MRT-B were created with their head tucked down (see Figure 1) could help to explain participants improved performance on Alexander and Evardone's human figures test but not on the MRT-B.

From the findings, it does not appear that embodied cognition improves the mental rotation of human figures on a Peters et al. (1995) type MRT, as both men's and women's overall mean proportion of correct responses decreased on the MRT-B compared to the MRT-R (see Table 1). Contrary to this finding, Amorim et al. (2006, Experiment 2) found that participants were faster and made fewer errors when mentally rotating human figures, even when the figures heads were held downwards (as it was implemented here), compared to performance on analogous Shepard and Metzler (1971) cubes. However, Amorim et al.'s (2006) test was likely easier as participants only had to compare one target item to one rotated item whereas the test used in the current study mirrored Peters et al.'s MRT and included one target item and an array of four response alternatives from which participants had to choose the two correct alternatives. If embodied cognition is in fact involved in the mental rotation of human figures, it appears that the underlying process does not help if a task is sufficiently difficult.

If embodied cognition does not play a role in mental rotation on a sufficiently difficult task, one would expect participants to perform similarly on both the MRT-R and the MRT-B. Yet participants actually performed better on the MRT-R than the MRT-B. This may be due to the fact that human figures are more complex, with more features than simple block figures. Birenbaum, Kelly, and Levi-Keren (1994) coded the attributes of different types of items used in a mental rotation task and found that complex stimuli with multiple spots or lines within the item proved more difficult to rotate than simple stimuli with fewer spots and lines. Birenbaum et al. proposed that individuals have more difficulty rotating more complex stimuli as these items may require more memory storage capacity in order to remember the item and its features when confirming whether alternatives are the same or different. The human figures rotated on the MRT-B contained a considerable amount of detail and may have required more working memory storage capacity in order to confirm whether response alternatives were correct than the simple line drawings of blocks rotated on the MRT-R. Heil & Jansen-Osmann's (2008) did not find a significant effect of complexity on participants' accuracy when rotating two dimensional polygons, yet they did find that mental rotation speed decreased when mentally rotating complex versus simple polygons. The increased complexity of human figures compared to block figures may help to explain participants' decreased performance when mentally rotating human figures on the MRT-B.

The present results could be refined in future studies by recording participants' response times on computerized versions of the MRT-R and MRT-B. This would allow a test of whether Amorim et al.'s (2006) response time findings are replicated on the MRT-R and the MRT-B. It would also be interesting to see if Heil & Jansen-Osmann's (2008) findings are replicated, with increased response times recorded on the more complex MRT-B items than on the simple MRT-R items.

It is also important to keep in mind that, in the current study, participants' accuracy on occluded and non-occluded MRT items as a function of stimulus type (bodies or blocks) was used to infer holistic and piecemeal mental rotation processes. Future studies might consider asking participants specifically what type of strategy they use to rotate human figures and determine if that strategy is different from the one used to rotate block items. This would essentially be the only way to obtain a direct assessment of strategy (but see Tapley & Bryden, 1977 on the potential value of such an approach).

Although the realism of the bodies in the MRT-B did not affect the findings obtained here in a meaningful way, it would be interesting to examine gender differences in mental rotation performance using photographs of real human bodies. It might also be interesting to essentially reverse the development of tests in the current study by creating block figures to match photographs of real human bodies. Performance on these tests might replicate the gender differences described by Alexander and Evardone (2008) as the task would likely be sufficiently simple. However, the magnitude of the gender difference in performance between this type of block MRT and the photographs of human bodies MRT would likely be smaller than that revealed by Alexander and Evardone (2008) as the block items made to imitate the photographs of human bodies would likely be simpler than the block items on the Peters et al. (1995) MRT.

In summary, the present results suggest that embodied cognition does not appear to improve participants' mental rotation abilities if the mental rotation task is sufficiently difficult. However, women are less hindered by occlusion when rotating human figures than when rotating blocks, possibly due to increased confidence and an increased propensity to guess (presumably, correctly). Future studies should aim to better understand the reduced effect of occlusion on women's MRT-B performance by examining empirically gender differences in confidence and propensity guess on occluded and non-occluded MRT-R and MRT-B items.

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Table 1

Mean Proportion of Correct Responses as a Function of Test, Occlusion, and Item Type and Gender (standard deviation in parentheses)

Variable	Men	Women	*d*
MRT-R	.75 (.23)	.56 (.27)	0.76
MRT-B	.65 (.23)	.54 (.22)	0.49
Occluded	.70 (.27)	.47 (.31)	0.79
Non-Occluded	.81 (.21)	.66 (.26)	0.63
Structural	.75 (.19)	.64 (.21)	0.55
Mirror	.66 (.24)	.47 (.27)	0.74

Note: d represents women's scores subtracted from men's scores divided by the pooled standard deviation (see Cohen, 1977).

Table 2

Mean Proportion of Correct Responses as a Function of Gender, Occlusion, and Test (standard deviation in parentheses)

Test / Occlusion	Men	Women	*d*
MRT-R			
Occluded	.70 (.27)	.47 (.31)	0.79
Non-Occluded	.81 (.21)	.66 (.26)	0.63
MRT-B			
Occluded	.61 (.28)	.49 (25)	0.45
Non-Occluded	. 70 (.22)	.59 (.22)	0.50

Note: d represents women's scores subtracted from men's scores divided by the pooled standard deviation (see Cohen, 1977).

Table 3

Mean Proportion of Correct Responses as a Function of Test, Distractor Type and Occlusion (standard deviations in parentheses)

Test / Distractor Type	Non-Occluded	Occluded	*d*
MRT-R			
Structural	.77 (.25)	.66 (.31)	0.39
Mirror	.69 (.30)	.49 (.36)	0.60
MRT-B			
Structural	.66 (.22)	.65 (.27)	0.04
Mirror	.61 (.29)	.43 (.32)	0.58

Note: d represents occluded item scores subtracted from non-occluded item scores divided by the pooled standard deviation (see Cohen, 1977).

Table 4

Summary of Results Relevant to Significant Interactions

Interaction	Pattern of Results
Gender x Test	Men outperformed women on both the MRT-R and the MRT-B but the magnitude of this gender differences was larger on the MRT-R (Table 1). Supports Hypothesis 1.
Gender x Occlusion	Men outperformed women on both occluded and non-occluded items, but the magnitude of this gender differences was larger on occluded items (Table 1). Supports Hypothesis 2.
Gender x Occlusion x Test	Gender differences in favour of men were significantly larger on occluded items than on non-occluded items, but only on the MRT-R (Table 2). Supports Hypothesis 4; Partial support Hypothesis 3.
Test x Occlusion among Women	There is a reduced effect of occlusion on women's performance on the MRT-B compared to the MRT-R (Table 2). Supports Hypothesis 4.
Gender x Distractor Type	Gender differences in favour of men were significantly larger for mirror distractor items than for structural distractor items (Table 3). Not hypothesized.

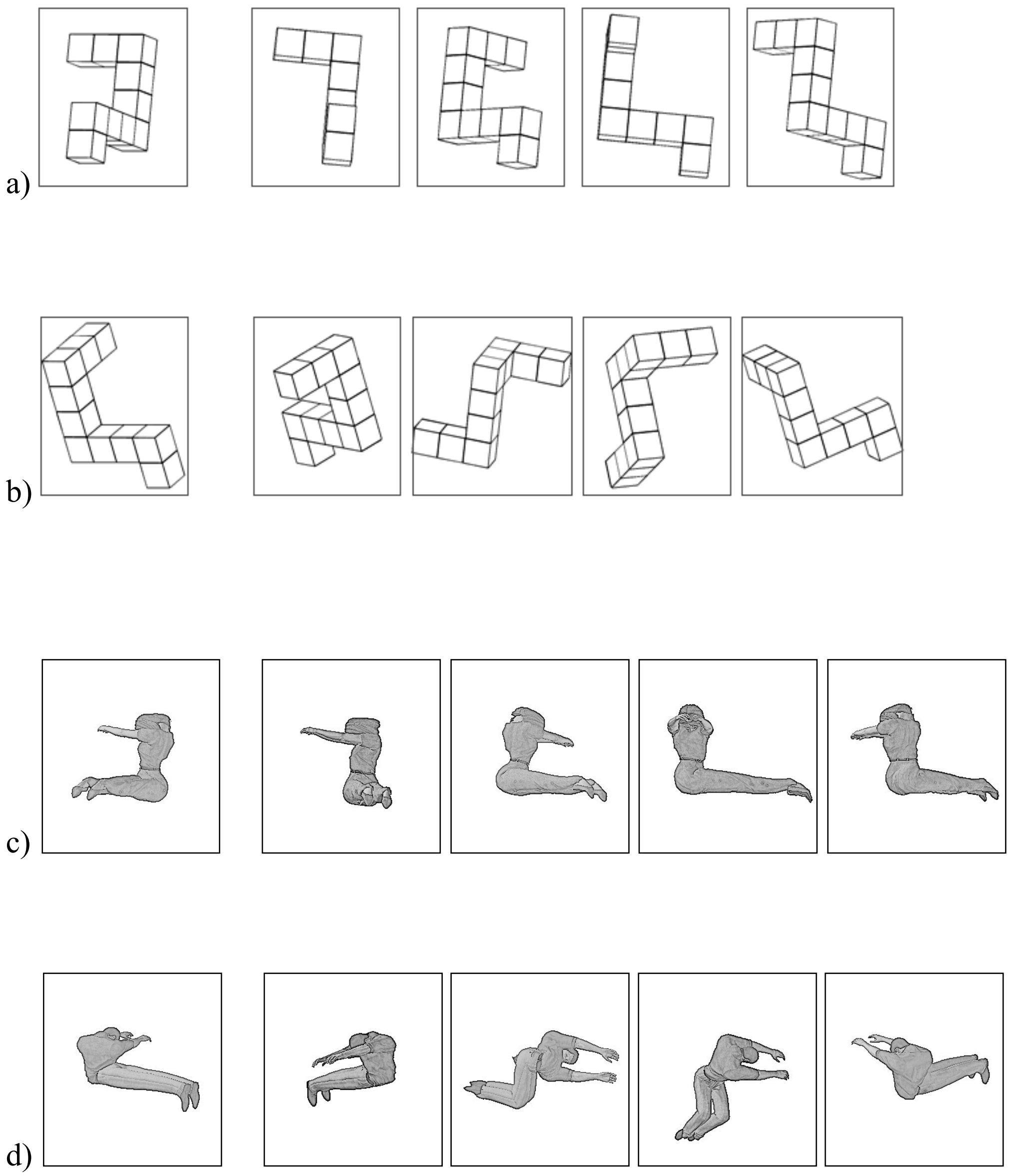

Figure 1. a) A mirror occluded item from the Revised MRT (MRT-R). Alternatives one and three are correct, whereas alternatives two and four are mirror images of the target item (distractors); the first alternative is occluded. b) A structural non-occluded item from the Revised MRT (MRT-R). Alternatives one and four are correct, whereas alternatives two and three are structurally different from the target item (distractors); no response

alternatives are occluded. c) A female mirror occluded item from the Bodies MRT (MRT-B) matching Item *a* above. d) A male structural non-occluded item from the Bodies MRT (MRT-B) matching item *b* above.

CHAPTER IV

Article II: Real bodies and occlusion: Item types, cognitive strategies, and gender differences in mental rotation

Abstract

The goal of the current study was to provide a better understanding of participants reduced accuracy when rotating human figures compared to block figures in Doyle and Voyer (2013), and the role of image familiarity, embodied cognition and cognitive strategies on gender differences in performance when rotating blocks and bodies. Two new MRTs were created: one using photographs of real human models positioned as closely as possible to computer drawn figures from the human figures MRT used in Doyle and Voyer (2013), and one using analogous block figures. It was hypothesized that, when compared to the analogous block figures, the real human figures would lead to improved accuracy among both men and women, a reduced magnitude of gender differences in accuracy, and a reduced effect of occlusion on women’s performance when compared to analogous block figures. The three-way interaction between test, gender and occlusion reported in Doyle and Voyer (2013) was not replicated in the current study. However, women's scores on the real human figures improved significantly more than men's scores on the real human figures test compared to the block figures test. This finding points to a greater strategy shift among women than men when rotating human figures.

Introduction

Gender Differences in Spatial Ability

It has been well established that, on average, men perform better than women on mental rotations tasks (Linn, & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). Mental rotation is the ability to quickly and accurately rotate a two dimensional (2D) or three dimensional (3D) object's spatial orientation in one's imagination (Linn, & Petersen, 1985; Voyer,et al., 1995). The redrawn Vandenberg and Kuse Mental Rotations Test (MRT) is likely the most common measure used in studies exploring individuals' mental rotation abilities (Peters, Laeng, Latham, Jackson, Zaiyouna, & Richardson, 1995). This pen-and-paper test involves comparing a target item to four response alternatives: two correct alternatives which are the same as the target item but rotated in space, and two distractor items that are different than the target item. The goal of this test is to identify the two correct response alternatives among a set of four figures when compared to a target drawing. Voyer et al. (1995) found that the magnitude of the gender difference in spatial performance were largest on mental rotation tasks, particularly Vandenburg and Kuse MRTs, compared to other spatial tasks.

The implications of gender differences in mental rotation are widespread. Most notably, performance on spatial tests has been correlated with mathematics achievement (Reuhkala, 2001; Rosselli, Ardila, Matute, & Inozemtseva, 2009), and performance on high stakes standardized tests such as the Scholastic Aptitude Test - Mathematics (SAT-M) (Bridgeman, & Wendler, 1991; Casey, Nuttall, Pezaris, & Benbow, 1995). Success on standardized tests such as the SAT-M is crucial to gain entry into science, technology, engineering, and mathematics (STEM) fields, particularly in the United States. Therefore, mental rotation abilities may have long lasting effects on an individual's career (Beede, Julian, Langdon, McKittrick, & Doms, 2011; Ferguson & Zhao, 2013).

The gateway to important, high paying STEM careers is, of course, a STEM degree, and the gateway to a STEM degree is acceptance into undergraduate and graduate degree programs, which often hinges on students' math grades and performance on high stakes tests such as the SAT-M. If women's reduced spatial abilities are having a negative impact on their math and SAT-M scores, it follows that helping women improve their spatial skills, and subsequently improve their math grades and SAT-M scores, could help to reduce the gender gap in STEM fields. To develop effective spatial skills training programs, we first need to uncover the factors that account for gender differences in spatial ability, particularly in mental rotation, an area in which the largest gender differences are found (Linn, & Petersen, 1985; Voyer et al., 1995).

Factors Associated with Gender Differences in Mental Rotation

What causes these gender differences in the mental rotation ability? The answer to this question is complex, involving many relational findings from different areas. Popular explanations offered in the research literature include biological factors, environmental factors, test characteristics, and strategy factors. Some of the biological factors that researchers have associated with gender differences in spatial ability include differences in brain structure and functioning (Hugdahl, Thomsen, & Ersland, 2006; Jordan, Wüstenberg, Heinze, Peters, & Jäncke; 2002), differences in prenatal and circulating hormones (Aleman, Bronk, Kessels, Koppeschaar, & van Honk, 2004; Berenbaum, Korman, & Leveroni, 1995; Hier, & Crowley, 1982), and genetic sex-related differences

(McGee, 1979; Vandenberg, 1969; Vuoksimaa, Viken, Hokkanen, Tuulio-Henriksson, Rose, & Kaprio, 2010).

Numerous environmental factors have also been proposed to explain gender differences in spatial ability, including childhood activities (Doyle, Voyer, & Cherney, 2012; Serbin, & Connor, 1979; Voyer, Nolan, & Voyer, 2000), and sex-role identification (McGlone, & Aronson, 2006; Sharps, Price, & Williams, 1994; Signorella, & Jamison, 1986; Wraga Duncan, Jacobs, Helt, & Church, 2006). There is also evidence that the magnitude of gender differences in mental rotation may be affected by variations in test administration procedure. Voyer, Rodgers, and McCormick (2004) showed an effect of timing conditions on guessing behavior as women displayed an increased propensity to guess when more time was available to complete the MRT items, yet men did not display this same propensity. Similarly Cooke-Simpson and Voyer (2007) found that confidence ratings were positively correlated with performance on the MRT, and lower confidence was related to increased guessing behaviour. Perhaps not surprisingly, in Cooke-Simpson and Voyer's study, men displayed both higher confidence ratings and higher MRT scores than women. Estes and Felker (2012) manipulated confidence levels and also found that participants randomly assigned to the high confidence group performed more accurately on the MRT than participants in the low confidence group, and women in the high confidence group performed as accurately as men in the low confidence group. The influence of administration procedure might reflect gender differences in cognitive strategy choices.

Cognitive Strategies. Gender differences in cognitive strategies have been linked with gender differences in spatial performance. Linn and Petersen (1985) suggested that

Gestalt like, global-holistic processing would provide a more effective cognitive strategy during mental rotation than a part-by-part analytic strategy. In support of this hypothesis, gender differences have been observed in the cognitive strategies used during mental rotation (e.g., Geiser, Lehmann, & Eid, 2009; Gluck, & Fitting, 2003; Heil, & Jansen-Osmann, 2008; Peters et al., 1995; Tzuriel, & Egozi, 2010). These studies suggest that, typically, men use a more holistic process when mentally rotating figures and they tend to synthesize visual information, imagine figures as a whole, and rotate the entire figure. In contrast, women use a more analytic process and tend to consider the individual parts or features of a figure and attempt to rotate the resulting piecemeal mental image. Although she did not examine gender differences in mental rotation strategy use, Schultz (1991) created a valid and reliable Spatial Strategies Questionnaire and found that endorsement of holistic strategies (e.g., move object) was predictive of higher spatial visualization scores, and endorsement of analytic strategies (e.g., focus on key features) was predictive of lower spatial visualization scores. Gender differences have been found in brain activation during mental rotation, which points to the possibility that men and women utilize different cognitive strategies. Men appear to use a more "hands on" approach to mental rotations, engaging the primary motor cortex to imagine physically moving the items, and women appear to use a more piecemeal process when mentally rotating items as they use the inferior temporal gyrus, involved in object-part identification (see Hugdahl et al., 2006, and Jordan et al., 2002).

Although there were no gender differences in performance in her study, Gluck (1999) reported gender differences in strategy use during a cube comparison test and a map test, with males reporting more holistic strategy use and women reporting more analytic strategy use, either alone or in combination with holistic strategies. Similarly, Heil and Jansen-Osmann (2008) examined the holistic and analytical approach to mental rotation with the use of simple and complex polygons. These researchers found that men performed faster when rotating both complex and simple polygons, but there was an increased gender difference in response times (RTs) for complex polygons rather than simple polygons. Heil and Jansen-Osmann (2008) believed this was because women used a more piecemeal approach; therefore, their RTs increased when complex polygons were rotated, as complex polygons contain more parts that must be processed.

Item Types. Mental Rotation Test (MRT) figure characteristics also play a role in gender differences in mental rotation speed and accuracy. Voyer and Hou (2006) were likely the first to analyze individual differences on four item types included in the Peters et al. (1995) MRT. These item types included MRT items that had mirror image distractors, items that had structurally different distractors, items that had occluded distractors or occluded correct alternatives, and nonoccluded items that did not have any occluded distractors or occluded correct alternatives (see Figure 1 on page 72 for an example of each item type). Voyer and Hou found decreased accuracy on occluded MRT items for both genders, reflecting the increased difficulty in mentally rotating these occluded items, and the magnitude of gender differences in mental rotation performance was larger for occluded than nonoccluded items. Voyer and Hou suggested that the increased magnitude of the gender difference in performance on occluded items could reflect the influence of the required 3D representation, or simply that the occluded items were more difficult than nonoccluded items. Voyer and Hou made note of the fact that the Peters et al. MRT does not contain an equal number of each item type, making variability a possible issue in their study. Although the results of Voyer and Hou's (2006) experiment did not yield a significant difference in performance between mirror and structural items, Bors and Vigneau (2011) found that mirror items were more difficult to rotate than structural items for both genders, and a gender by distractor type interaction was also found, with a greater magnitude of gender differences in accuracy on the mirror items than structural items. Bors and Vigneau also replicated Voyer and Hou's occlusion findings.

Using a different approach to item type manipulation, Alexander and Evardone (2008) found that, in comparison to gender differences on the Peters et al. (1995) MRT, the magnitude of the gender difference in mental rotation accuracy diminished by approximately half when participants mentally rotated 3D human figures. Although the authors considered social and hormonal factors as possible sources of these diminished gender differences, specific causes remained unclear. Alexander and Evardone's block and human items may have been mismatched in difficulty level; therefore, performance on the block figures and human figures used in their study cannot necessarily be considered comparable.

Item Familiarity. The familiarity of the items to be mentally rotated has also been found to affect gender differences in performance. Sharps et al. (1994) had male and female participants mentally rotate simple, familiar items and more complex, unfamiliar items. Sharps et al. found gender differences in mental rotation performance on complex, unfamiliar items, but differences did not emerge in mental rotation performance of simple, familiar items.

As mentioned earlier, Heil and Jansen-Osmann's (2008) used simple and complex polygons and found that rotating more complex polygons resulted in reduced accuracy and increased RTs when compared to less complex polygons. It is important to note that Heil and Jansen-Osmann reported that polygon familiarity did not have an effect on mental rotation performance. Related to this finding, Amorim, Isableu, and Jarraya (2006) found that rotating desk lamps, which would be highly familiar but complex objects, resulted in similar error rates and RT scores to rotating blocks, which are unfamiliar but simple objects. These results from Heil and Jansen-Osmann (2008) and Amorim et al. (2006) suggest that the complexity of objects may have more impact on mental rotation performance than their familiarity. Taken together with all of the studies discussed, the results from the literature appear to be mixed.

Embodied Cognition

One could argue that there are few things in life as familiar to an individual as their own body, both in terms of its physical makeup and its place in space. It is also plausible to argue that the human body is almost always considered one whole object. That is, we generally view the human body as one unit rather than as a complex combination of separate body parts. It is because individuals seem to have a special connection with their body and its orientation in the environment that cognitive researchers began considering the influence of the human body on thought processes (including mental rotation), and began developing theories related to *embodied cognition* (Anderson, 2003).

Recently, embodied cognition has been added to the list of factors relevant to gender differences in spatial abilities. Wilson (2002) noted that mental structures that were originally evolved for perception or action may be separated from that initial purpose and used to aid in cognitive processing, including mental rotation. To make mental rotations easier, individuals may be able to call on the sensorimotor system and imagine that a block figure to be rotated is analogous to a human body being rotated (Amorim et al., 2006). Using embodied cognition might also help individuals to engage in more holistic processing and subsequently improve their spatial performance, as the human body is typically considered as a whole, while abstract figures, such as blocks, can easily be considered in a more piece-meal, analytic fashion.

To better understand the role of embodied cognition on mental rotation processes, Doyle and Voyer (2013) compared male and female performance on a novel block MRT (MRT-R), and a novel human figure MRT (MRT-B). The MRT- R was created with an equal numbers of occluded, non-occluded, structural and mirror block items, and the MRT-B was a directly analogous version of the MRT-R, developed using computer drawn human figures as opposed to blocks. Creating tests with equal numbers of each item type was expected to reduce the large amount of variability in accuracy seen in Voyer and Hou (2006; for example, see Table 1 of their paper). In addition, unlike the Alexander and Evardone's (2008) study in which the human figures were positioned with their arms and legs protruding are various angles and bent in various ways, the computer generated human figures created for the MRT-B were bent at the waist, knees, hips, and ankles to make the figures as analogous to the block items on the MRT-R as possible.

Contrary to the results reported by Alexander and Evardone (2008), Doyle and Voyer (2013) found that both men and women performed less accurately when rotating the human figures on the MRT-B than when rotating the block figures on the MRT-R.

The authors suggested that this result may be due to the fact that the human figures on the MRT-B were more complex than the block figures on the MRT-R. As mentioned previously, the complexity of an object (i.e., the desk lamps in Amorim et al., 2006) has a greater effect on mental rotation performance than familiarity of the object being rotated (Heil & Jansen-Osmann, 2008b). Doyle and Voyer (2013) also found that the effect of occlusion on the MRT performance of females was reduced on the MRT-B compared to the MRT-R, which Doyle and Voyer suggested was the result of embodied cognition. Women appeared to engage a more holistic approach when rotating human figures than when rotating block figures, reducing the effect of occlusion, whereas the effect of occlusion on men's MRT performance remained the same across both the MRT-R and the MRT-B, as men likely used a holistic approach regardless of the stimuli presented.

Current Study

The goal of the current study was to provide a better understanding of participants reduced accuracy when rotating human figures on the MRT-B and the role of image familiarity, embodied cognition and cognitive strategies on gender differences in performance when rotating blocks and bodies. The primary question of interest was: *If human figures are more realistic (i.e., familiar, realistic biological movements), will participants be able to better engage embodied cognition and holistic processing, and improve their mental rotation scores compared to performance on analogous block figures?* Relevant research suggests that when body parts are shown in positions that are difficult to replicate with one's own body, they are more difficult to mentally rotate than body parts that are presented in anatomically correct and comfortable, common postures (Cooper, & Shepard, 1975; Doyle & Voyer, 2013; Parsons, 1987). It appears that it is easier to engage in embodied cognition when the stimuli closely approximate one's own body's capabilities. Therefore, participants from Doyle and Voyer (2013) may have had a difficulty engaging in embodied cognition and mentally rotating images from the MRT-B as the computer drawn human figures were created by bending the shoulders, waists, hips, knees, and ankles at 90° angles. This often lead to the creation of human figures that, while closely resembling the block figures on the MRT-R, were positioned in contortions that are not humanly possible (see Figure 1). Therefore, important questions remained to be answered: (1) Would the gender difference in mental rotation be reduced if participants were rotating realistic human figures?; (2) Would embodied cognition, and subsequently holistic processing strategies, be more readily engaged when rotating realistic human figures?; and, (3) Would the effect of occlusion be reduced to a greater extent when rotating realistic human figures than when rotating analogous block figures, as compared to the reduced effect of occlusion when rotating computer drawn human figures (reflecting an increased propensity to engage holistic processing)?

To address these outstanding research questions, a new MRT was created using real human figures (photographs of real human models positioned as closely as possible to computer drawn figures from the MRT-B). It was hypothesized that these realistic, anatomically correct human figures would encourage embodied cognition and holistic processing more so than the computer drawn MRT-B items. Accordingly, it was hypothesized that when compared to analogous block figures, these real human figures would lead to improved mental rotation performance among both men and women, reduce the magnitude of gender differences in mental rotation, and reduce the effect of occlusion on women's performance when compared to analogous block figures.

Method

Participants

A power analysis was conducted using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) based on the effect sizes obtained in Doyle and Voyer (2013) of $\eta^2 = .02$ ($f = .04$). To obtain an effect size of Cohen's $f = .04$ at a significance level of .05 achieving power at 95%, the study required a total of 108 participants (54 of each gender). Therefore, 131 Introductory Psychology students (66 males, 65 females) between the ages of 17 and 36 (M = 20.28, SD = 3.2) were tested. The sample included mainly Caucasian (80.2%) and Asian (8.4%) individuals. Participation was voluntary and in exchange for their time, participants received one point towards their Introductory Psychology grade. The only exclusion criterion was that participants were required to have normal or corrected to normal vision in both eyes. This study was approved by the institutional Research Ethics Board. Data from one female participant was removed as she only completed two pages of the test booklet during a 45 minute testing period, resulting in a total of 34 females in the final sample.

Materials

MRT-B2. A new MRT was created using real human models (one male and one female) posed as close as possible to six different items from the MRT-B used in Doyle and Voyer (2013). The models were photographed holding the poses while spinning on a rotating platform in order to shoot each pose at 360°, in 20° intervals. The pen-and-paper test created was modeled after the original Vandenberg and Kuse (1978) MRT, with 24 items, each including one target figure and four response alternatives. There were 12 items created using the male model and 12 items using the female model. Following the format of the MRT-R and MRT-B from Doyle and Voyer (2013), the response alternatives on this new MRT included equal numbers of mirror occluded, mirror nonoccluded, structural occluded and structural nonoccluded items, resulting in six of each item type included on the test. See Figure 2a for an example of a mirror occluded MRT-B2 item. As in the original MRT (Vandenberg & Kuse, 1978), identifying both correct response alternatives resulted in one point whereas any other response results in no points. The maximum possible score was 24.

MRT-R2. A new blocks MRT was created, using the Peters et al. (1995) block figures that were directly analogous to the real human figures on the MRT-B2. See Figure 2b for an example of a mirror occluded MRT-R2 item analogous to the real human figure presented in Figure 2a. As in the original MRT (Vandenberg & Kuse, 1978), identifying both correct response alternatives resulted in one point whereas any other response results in no points. The maximum possible score was 24.

Demographics. Participants indicated their gender (male or female), age, and ethnicity. Participants also indicated how much physical activity they engaged in each week, and identified any physical health conditions that applied to them.

Procedure

The procedure replicated Doyle and Voyer (2013), using the MRT-R2 and the MRT-B2 as opposed to the MRT-R and the MRT-B. Participants were tested in a room specially designed for small group testing, with a maximum of four participants per testing session. Each participant was seated at a desk flanked by dividers. Two versions of test booklets were administered; each began with the MRTs (the MRT-R2 and the MRT-B2 were presented in a counterbalanced order), and the demographics form was always completed last. After signing a consent form, participants received their test booklet and the experimenter read the instructions for the MRT aloud, giving participants time to complete the practice questions. Participants were instructed to put their pen down after completing the first MRT. After all participants completed the first MRT, the experimenter read the instructions for the second MRT aloud, again giving participants time to complete the practice questions. Upon completion of the second MRT, participants completed the demographics questionnaire. Finally, the experimenter concluded the experiment by distributing a debriefing sheet to each participant. Both the MRT-R2 and the MRT-B2 were administered without time limits so that participants had the opportunity to complete all test items.

Results

Preliminary Analyses

Basic demographic information was obtained to describe the sample (see Participants section). Preliminary analyses correlated the amount of physical activity with accuracy. Because amount of physical activity was not correlated with accuracy on the MRT-R2 (r_s = -0.063, p = .478) or the MRT-B2 (r_s = .075, p = .398), it was not entered as a covariate in further analyses. In addition, only 10 individuals reported physical health concerns; removing these individuals from the data set did not affect statistically significant main effects or interactions, therefore the data from individuals who reported health concerns were included in the main analyses.

Main Analyses

To address the hypotheses, the proportion of correct responses on the MRT-R2 and MRT-B2 were the dependent variables in a mixed-design ANOVA with gender of participants (men, women), test (MRT-R2 vs. MRT-B2), occlusion (occluded vs. non-occluded), and distractor type (mirror vs. structural) as independent variables. For each significant interaction in ANOVA, simple main effects were analyzed based on the approach recommended by Winer (1962). Effect sizes for gender differences were calculated as performance for men minus performance for women divided by the pooled standard deviation (Cohen's *d*; Cohen, 1997).

In line with the hypotheses, a main effect of test, $F(1, 128) = 47.30$, $p < .001$, $\eta_p^2 = .27$, reflected increased accuracy on the MRT-B2 (M = 0.83, SD = 0.16) compared to the MRT-R2 (M = 0.73, SD = 0.18). There was a main effect of gender, $F(1, 128) = 32.55$, $p < .001$, $\eta_p^2 = .20$, with males performing more accurately (M = 0.86, SD = 0.15) than females (M = 0.70, SD = 0.15). There was also a main effect of occlusion, $F(1, 128) = 39.80$, $p < .001$, $\eta_p^2 = .24$, with participants performing more accurately on nonoccluded items (M = 0.81, SD = 0.16) than on occluded items (M = 0.75, SD = 0.16), and a main effect of distractor type, $F(1, 128) = 199.06$, $p < .001$, $\eta_p^2 = .61$, with participants performing more accurately on items with structural distractors (M = 0.87, SD = 0.12) than on items with mirror distractors (M = 0.69, SD = 0.20).

All main effects were qualified by significant interactions. A test by gender interaction, $F(1, 128) = 4.78$, $p = .031$, $\eta_p^2 = .04$, resulted from a reduced gender difference in accuracy on the MRT-B2, $F(1, 128) = 17.75$, $p < .001$, $\eta_p^2 = .12$, compared to the MRT-R2, $F(1, 128) = 34.20$, $p < .001$, $\eta_p^2 = .21$ (see Table 1 for means related to this interaction). A distractor type by gender interaction, $F(1, 128) = 37.75$, $p < .001$, $\eta_p^2 = .23$, resulted from a reduced gender difference in accuracy on items with structural distractors, $F(1, 128) = 12.11$, $p = .001$, $\eta_p^2 = .09$, compared to items with mirror distractors, $F(1, 128) = 40.84$, $p < .001$, $\eta_p^2 = .24$ (again, see Table 1 for means related to this interaction). Finally, a test by occlusion interaction, $F(1, 128) = 7.22$, $p = .008$, $\eta_p^2 = .05$, reflected a reduced effect of occlusion on the MRT-B2, $F(1, 128) = 12.66$, $p = .001$, $\eta_p^2 = .09$, compared to the MRT-R2, $F(1, 128) = 31.50$, $p < .001$, $\eta_p^2 = .20$ (see Table 2 for means related to this interaction). No other main effects or interactions reached statistical significance, including the hypothesized test by gender by occlusion interaction, $F(1, 128) = 1.59$, $p = .21$, $\eta_p^2 = .01$.

Discussion

Two new versions of the MRT were created to investigate gender differences in mental rotation strategies and performance, one using Peters et al. (1995) MRT block figures (MRT-R2) and another using photos of real human figures positioned as closely as possible to these block figures (MRT-B2). First, it was hypothesized that both men and women would perform more accurately on the real human figures MRT-B2 than on the analogous block figures MRT-R2. Second, it was hypothesized that gender differences in accuracy would be reduced on the MRT-B2 compared to the MRT-R2. Third, it was hypothesized that, particularly among women, there would be a reduced effect of occlusion on accuracy on the real human figures MRT-B2 compared to the analogous block figures MRT-R2.

The rationale underlying the first hypothesis was that the real human figures on the new MRT-B2 would encourage more reliance on embodied cognition and, in turn, holistic processing than the computer drawn “impossible” human figures on the MRT-B administered in Doyle and Voyer (2013). The first hypothesis was supported as participants’ performance improved on the real human figures on the MRT-B2 compared to the analogous block figures on the MRT-R2 (see Table 1), whereas in Doyle and Voyer, performance on the computer drawn human figure MRT-B actually decreased compared to performance on the analogous block figure MRT-R. Previous research suggests that embodied cognition is more readily engaged when stimuli are presented in humanly possible postures that can be easily imitated by the participant (Amorim et al., 2006; Cooper & Shepard, 1975; Parsons, 1987). This helps to explain why results from Doyle and Voyer did not replicate the improved performance on a human figures MRT compared to a block figures MRT that was reported by Alexander and Evardone (2008).

Although Alexander and Evardone's (2008) human figure MRT was not directly analogous with their block figures MRT, the computer drawn human figures included on their MRT were all positioned in poses that were anatomically correct and possible for participants to imitate. In contrast, the computer drawn human figures on the MRT-B administered in Doyle and Voyer (2013) were created to resemble the block figures on the MRT-R as closely as possible, which often led to the creation of computer drawn human figures that were contorted into poses that would be impossible for participants to actually imitate. This may have made it more difficult for participants from Doyle and Voyer to engage embodied cognition and subsequently improve their performance when mentally rotating the human figures on the MRT-B.

Furthermore, a recent study by Krüger, Amorim, and Ebersbach (2014) illustrated that, not only do impossible human figures hinder the use of embodied cognition, resulting in reduced mental rotation performance compared to possible human figures, but impossible human figures actually appear to be *more* difficult to mentally rotate than analogous block figures. Krüger et al. argued that participants might lack the cognitive flexibility to ignore the anatomically incorrect body parts in order to process the impossible human figures in a manner similar to regular block figures. Krüger et al.'s finding that impossible human figures are more difficult to rotate than block figures, as indicated by increased response times and lower speed of rotation when rotating impossible human figures, helps to explain the reduced accuracy across men and women from Doyle and Voyer (2013) on the computer drawn human figures compared to the analogous block figures test. Perhaps participants from Doyle and Voyer were unable to ignore unrealistic, anatomically incorrect human figures on the MRT-B, and tried unsuccessfully to use embodied cognition when rotating those figures. If participants could successfully engage in embodied cognition when rotating plausible human figures on the MRT-B2, the higher accuracy on the human figures MRT-B2 compared to the analogous block figures MRT-R2 would be expected.

In agreement with the second hypothesis, the magnitude of gender differences in mental rotation was reduced when real bodies were used as stimuli. Specifically, the performance of both males and females improved on the real human figures MRT-B2 compared to their performance on the block figures MRT-R2 but, as reflected in the test by gender interaction and in the means in Table 1, the magnitude of improvement on the real human figure MRT-B2 was significantly larger for women than men. In fact, the effect sizes in Table 2 suggest that the male advantage was reduced on the MRT-B2 compared to the MRT-R2. This test by gender interaction therefore fits with the notion that women might switch from a piecemeal strategy when rotating block figures to a holistic strategy when rotating human figures. It is possible that the scores of the females on the human figures MRT-B2 improved more so than males scores because, as reported in Doyle and Voyer (2013), men on average are more likely to use holistic processing strategies on both block and human figure MRTs. However, underlying embodied cognition might encourage women to switch from a less successful piecemeal strategy when rotating the block figures on the MRT-R2 to a more successful holistic strategy when rotating the human figures on the MRT-B2, as we expected.

The third hypothesis predicted that, for women, there would be a reduced effect of occlusion on performance on the real human figures MRT-B2 when compared to the effect of occlusion on the analogous block figures on the MRT-R2. This reduced effect of occlusion across tests was not hypothesized to be significant among men. This three-way interaction reported in Doyle and Voyer was not replicated. The reduced effect of occlusion on MRT-B2 did not significantly differ across genders. With real human figures, the switch of strategy was found for all items, not just occluded items. The reduced effect of occlusion on the computer-drawn human figures on the MRT-B reported by Doyle and Voyer (2013) may have simply been due to the increase difficulty of those computer-drawn figures. Therefore, real human figures presumably achieved an application of holistic processing for all stimuli, not a select few.

The failure to replicate the test by gender by occlusion interaction reported in Doyle and Voyer (2013) may be a result of the use of more realistic stimuli to promote embodied cognition and holistic processing. However, the absence of this interaction could also be due to ceiling effects. Specifically, the effect of occlusion appears to be reduced among both men and women on the real human figures MRT-B2 compared to the block figures MRT-R2. Among men, the reduced effect of occlusion on the MRT-B2 may be a result of male participants hitting a performance ceiling whereby they simply could not score higher on the nonoccluded real human figures. Among men, accuracy on nonoccluded real human figures was 91%, with 32 of the 66 male participants scoring perfectly compared to just 16 of the 64 female participants scoring perfectly on these items. Normally, in order to deal with ceiling effects one would make the task more difficult so that participants do not easily obtain the highest score possible. However, it would be impossible to make the MRT-B2 more difficult without altering the items that were designed to be as analogous as possible to those on the MRT-R2 and running the risk of potential floor effects for female participants.

An interesting point to note is that, although the MRT-B2 and MRT-R2 appear to be easier than the MRT-B and MRT-R used in Doyle and Voyer (2013; compare Table 1 from Doyle and Voyer, and Table 1 in the current experiment), this lower level of difficulty did not reduce or eliminate gender differences in performance. In fact, gender differences on both the MRT-R2 (d = 1.00) and the MRT-B2 (d = .73) are larger than the gender differences on the MRT-R (d = .71) and the MRT-B (d = .48). However, the reduced variability among the MRT-R2 and MRT-B2 scores are a further reflection of ceiling effects on these test scores (see Table 2 from Doyle and Voyer and current Table 1).

A limitation of the current and previous studies (Alexander & Evardone, 2008; Amorim et al., 2006; Krüger, Amorim & Ebersbach, 2014) is the reliance on behavioral data that involve inferring the strategies men and women use based on patterns of accuracy and response time on certain MRT item types. To support the findings from the present study and other behavioural studies, future research could administer the MRT-B2 and the MRT-R2 while tracking eye movements. If embodied cognition does in fact encourage participants to use holistic processing strategies, one would expect to find that participants use fewer saccades (eye movements) when comparing real human figure targets to response alternatives, than when comparing block figure targets to response alternatives (Shiina, Saito & Suzuki, 1997). A reduced number of saccades would result if participants encode human figure targets as a whole and spend less time reviewing specific features of the human figure when comparing it to the response alternatives. In addition, if women switch from a piecemeal strategy when rotating block figures to a holistic strategy when rotating human figures, among women one would expect to see a reduction in the number of eye movements on the human figures MRT-B2 compared to the block figures MRT-R2; among men, the number of eye movements should not be significantly different across tests. In addition to adding support to behavioural data such as accuracy and response time, using eye tracking data to study individual differences in spatial strategy would help to avoid issues inherent to self-report measures of spatial strategy such as the low level of variability accounted for when using spatial strategy questionnaires (Schultz, 1991; Tapley & Bryden, 1977).

In conclusion, human figures appear to encourage the use of embodied cognition and holistic processing, which in turn lead to improved performance among both men and women on mental rotation tasks. The significantly larger improvement in women's than men's scores on the MRT-B2 compared to the MRT-R2 points to a greater strategy shift among women than men when rotating human figures. In light of these findings, it seems it would be a worthwhile to develop mental rotation training programs that encourage individuals to use holistic processing strategies when rotating all figures, human or otherwise. If successful, such training programs would help individuals struggling with mental rotation and could conceivably help to decrease the persistent gender difference in mental rotation (Voyer et al., 1995).

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Table 1

Mean Proportion of Correct Responses as a Function of Test, Distractor Type, and Gender

IV		Men	Women	*d*
Test	MRT-R2	.82 (.18)	.64 (.18)	1.00
	MRT-B2	.89 (.16)	.77 (.17)	0.73
Distractor	Mirror	.80 (.20)	.57 (.21)	1.12
	Structural	.91 (.12)	.83 (.12)	0.67

Note. IV = independent variable. *d* = Cohen's d reflecting men's mean score minus women's mean score divided by the pooled standard deviation. Standard deviations in parentheses.

Table 2

Mean Proportion of Correct Responses as a Function of Test and Occlusion

	Nonoccluded	Occluded	*d*
MRT-R2	.77 (.19)	.69 (.20)	0.41
MRT-B2	.85 (.17)	.81 (.17)	0.24

Note. d = Cohen's d reflecting mean score on nonoccluded items minus mean score on occluded items divided by the pooled standard deviation. Standard deviations in parentheses.

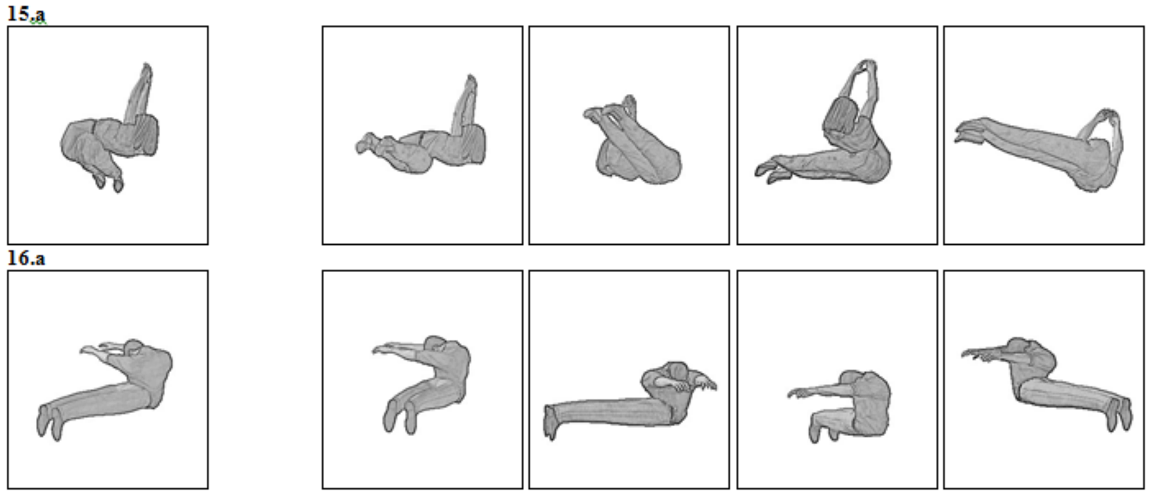

Figure 1. An example of a female (above) and male (below) impossible MRT-B human figure from Doyle and Voyer (2013).

a)

b)

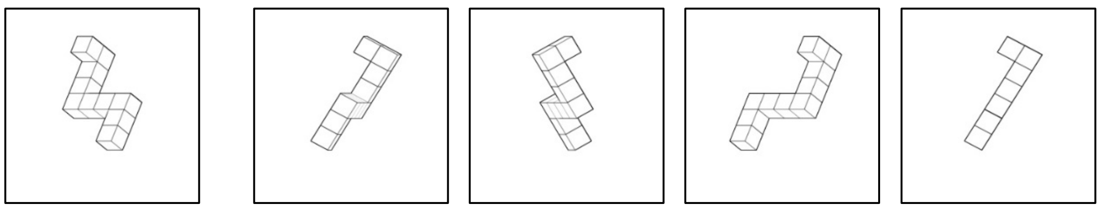

Figure 2. a) A mirror occluded item from the MRT-B2. Alternatives one and two are correct, whereas alternatives three and four are mirror images of the target item (distractors); the fourth alternative is occluded. b) An analogous mirror occluded item from the MRT-R2. Alternatives one and two are correct, whereas alternatives three and four are mirror images of the target item (distractors); the fourth alternative is occluded.

GENERAL DISCUSSION

In two studies, novel MRTs were created using computer-drawn and real human figures, and analogous block figures in order to gain a better understanding of embodied cognition and gender differences in mental rotation. In the first study, Doyle and Voyer (2013) found a reduced effect of occlusion on the performance of females when rotating computer drawn human figures compared to analogous block figures, whereas for males, the effect of occlusion on performance was similar across item types. This reduced effect of occlusion among women may be due to embodied cognition encouraging women to switch from a piecemeal mental rotation strategy when rotating block figures to a more holistic strategy when rotating human figures.

In Doyle and Voyer (2013; Article I), one perplexing finding was reduced accuracy, for both men and women, on the computer-drawn human figure MRT compared to the block figure MRT. This finding contrasted with results of previous studies using human figure with the MRT (Alexander & Evardone, 2008; Amorim et al., 2006). Doyle and Voyer proposed that this reduced accuracy may have been due to the unrealistic nature of the computer drawn human figures used on their MRT-B. In order to investigate the role of realism of the human figures on embodied cognition and holistic processing strategies, and gender differences in mental rotation, Article II included a novel MRT created using real human models posed as closely as possible to the computer drawn human figures from Doyle and Voyer's MRT-B.

Results from Article II indicate greater ease rotating real human figures compared to analogous blocks as all participants performed more accurately on the real human figures MRT-B2 than on the analogous block figures MRT-R2. In addition, gender differences in favour of men decreased on the MRT-B2 compared to the MRT-R2, and the effect of occlusion was reduced on the MRT-B2 compared to the MRT-R2. The combination of these results suggest that both men and women are able to better engage embodied cognition and use more holistic processing strategies when rotating real human figures. However, women benefit more from this shift in strategy than do men, possibly because men tend to favor a holistic strategy regardless of stimulus type. Taken together, this finding fits with Wilson's (2002) assertion that mental structures that were originally evolved for perception or action may be separated from their initial purpose and used to aid in cognitive processing, including mental rotation. Indeed, embodied cognition appears to be more readily engaged when the stimuli closely approximate one's own body, and using embodied cognition helps individuals improve their mental rotation performance.

Limitations

A limitation of the studies reported in this dissertation, and of previous studies (Alexander & Evardone, 2008; Amorim et al., 2006; Krüger, Amorim & Ebersbach, 2014), is their reliance on behavioral data, inferring the strategies men and women based on patterns of accuracy and response time on certain MRT item types. Moving forward, future studies should use eye tracking data to add further support to the behavioural findings reported here. If embodied cognition does in fact encourage participants to use holistic processing strategies, one would expect to find that participants use fewer saccades (eye movements) when comparing real human figure targets to response alternatives, than when comparing block figure targets to response alternatives (Shiina, Saito, & Suzuki, 1997). In addition to adding support to behavioural data such as accuracy and response time, using eye tracking data to study individual differences in spatial strategy would help to avoid issues inherent to self-report measures of spatial strategy such as the low level of variability accounted for when using spatial strategy questionnaires (Schultz, 1991; Tapley & Bryden, 1977).

Implications

One of the implications of gender differences in mental rotation is that performance on spatial tests has been correlated with mathematics achievement (Reuhkala, 2001; Rosselli, Ardila, Matute, & Inozemtseva, 2009), and performance on high stakes standardized tests such as the Scholastic Aptitude Test - Mathematics (SAT-M) (Bridgeman, & Wendler, 1991; Casey, Nuttall, Pezaris, & Benbow, 1995). Success on standardized tests such as the SAT-M is crucial to gain entry into science, technology, engineering, and mathematics (STEM) fields, particularly in the United States. Therefore, mental rotation abilities may have long lasting effects on an individual's career (Beede, Julian, Langdon, McKittrick & Doms, 2011; Ferguson & Zhao, 2013). In light of this outcome, it would be useful to develop training programs that encourage individuals to use embodied cognition and holistic processing strategies regardless of the type of task one is performing. If embodied cognition and holistic processing strategies can be effectively trained, it could help all individuals struggling with mental rotation. Such training programs might also help reduce gender differences in mental rotation, and encourage more women to enter science, technology, engineering and mathematics fields (Uttal, et al,, 2013).

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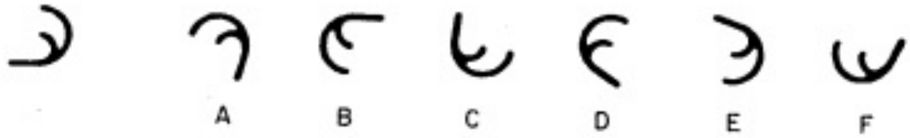
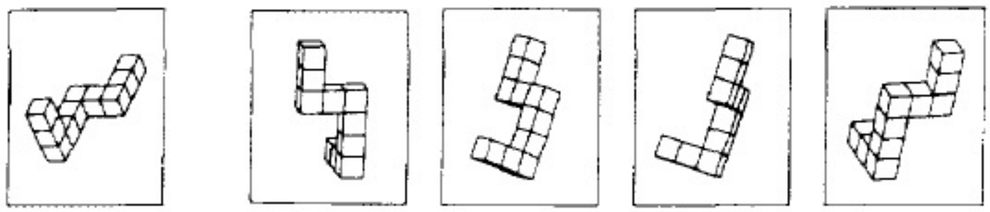


a)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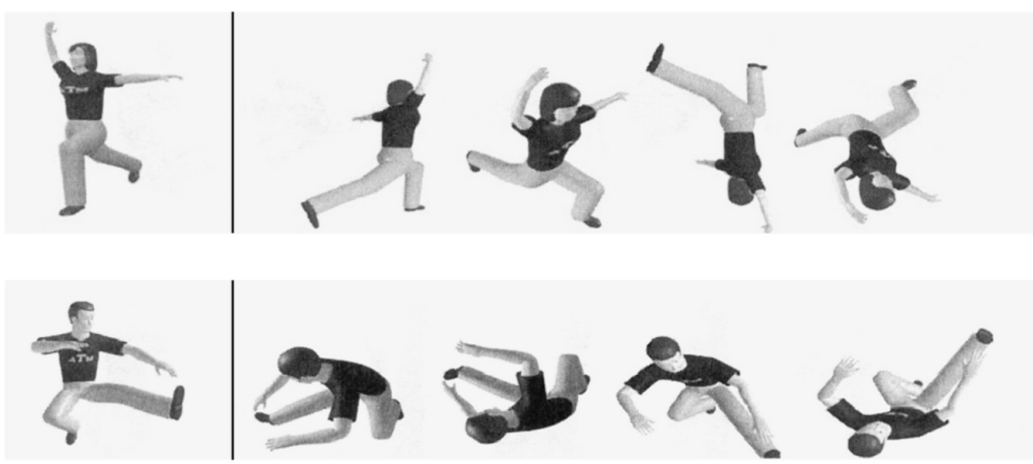
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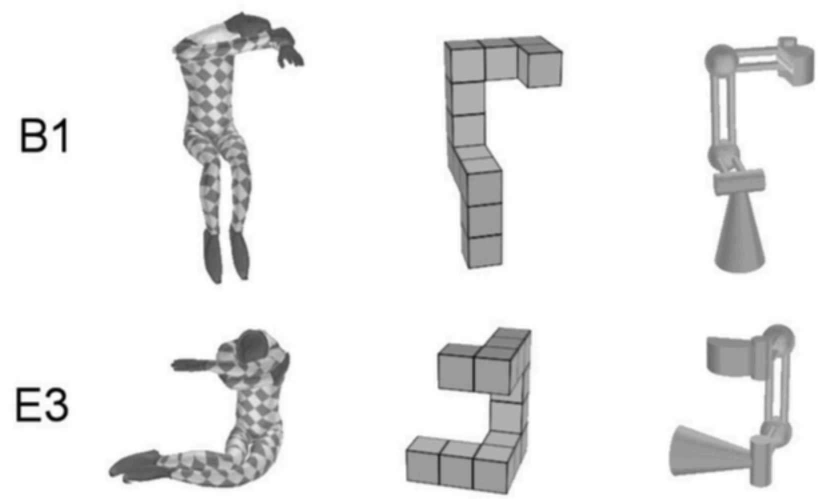

d)

Figure 1. a) An example of a mental rotation item from Thurstone's (1941) Primary Mental Abilities Space test (Schaie, 1979). b) An example of a mental rotation item similar to the Vandenberg and Kuse (1978) Mental Rotations Test (Peters, et al., 1995). c) An example of female and male human figure mental rotation items from Alexander and Evardone (2008). d) And example of analogous human figures, blocks, and desk lamps from Amorim et al. (2006).

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PUBLICATIONS

Doyle, R. A., Voyer, D., & Lesmana, M. (in press). Item type, occlusion, and gender differences in mental rotation. *Quarterly Journal of Experimental Psychology.* doi: 10.1080/17470218.2015.1086807

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CONFERENCE PRESENTATIONS

Doyle, R. A., & Ronis, S. (2015, July). *Qualitative study of early sexual experiences and* *the conceptualization of consent.* Moderated poster and oral presentation presented at the 22nd Congress of the World Association for Sexual Health (WAS), Singapore, Singapore.

Doyle, R. A., & Ronis, S, Garceau, C. (2015, July). *Early sexual experiences and real and ideal parent-child communications about sex.* Poster presented at the 22nd Congress of the World Association for Sexual Health (WAS), Singapore, Singapore.

Doyle, R. A., & Voyer, D. (2015, June). *Real bodies and occlusion: Item types, cognitive strategies, and gender differences in mental rotation.* Poster presented at the 2015 Canadian Society of Brain, Behaviour and Cognitive Science (CSBBCS) Conference, Ottawa, ON.

Doyle, R. A., & Voyer, D. (2014, October). Stereotype manipulation effects on math and spatial test performance. Poster presented at the 10th Annual Gender Development Research Conference (GDRC), San Francisco, CA.

Doyle, R. A., & Voyer, D. (2014, July). *Mental rotation accuracy and response time on occluded and nonoccluded blocks and bodies.* Poster presented at the 2014 Canadian Society of Brain, Behaviour and Cognitive Science (CSBBCS) Conference, Toronto, ON.

Stevanovski, B., & **Doyle, R. A.** (2014, July). *Central attentional resource requirements for encoding sequential versus simultaneous displays in visual short-term memory.* Oral presentation at the 2014 Canadian Society of Brain, Behaviour and Cognitive Science (CSBBCS) Conference, Toronto, ON.

Doyle, R. A., & Voyer, D. (2013, June). *Bodies and occlusion II: Item types, cognitive strategies, and gender differences in mental rotation.* Poster presented at the 2013 Canadian Psychological Association (CPA) Convention, Quebec City, QC.

Doyle, R. A., & Voyer, D. (2012, November). *The effect of stereotype instruction manipulations on men's and women's math and spatial test performance: Two meta-analyses.* Poster presented at the 2012 Psychonomic Society Annual Meeting, Minneapolis, MN.

Doyle, R. A., & Voyer, D. (2012, June). *Gender differences in math performance under stereotype threat: A meta-analysis.* Poster presented at the 2012 Canadian Psychological Association (CPA) Convention, Halifax, NS.

Doyle, R. A., & Voyer, D. (2011, November). *Item types, cognitive strategies, and gender differences in mental rotation.* Poster presented at the 2011 Psychonomic Society Annual Meeting, Seattle, WA.

Doyle, R. A., & Voyer, D. (2011, June). *Response time as a predictor of gender* *differences on a computerized Mental Rotations Test.* Poster presented at the 2011 Canadian Psychological Association (CPA) Convention, Toronto, ON.

Doyle, R. A., Voyer, D., & Cherney, I. D. (2011, April). *Development of a spatial activity questionnaire II: Validation.* Poster presented at the 2011 Society for Research in Child Development (SRCD) Biennial Meeting, Montreal, QC.

Doyle, R. A. (2010, June). *Type of distractors and magnitude of gender differences in reaction times on a computerized Mental Rotations Test.* Poster presented at the 2010 Canadian Society of Brain, Behaviour and Cognitive Science (CSBBCS) Conference, Halifax, NS.