Factors Mediating the Sex
Difference Observed In
Targeting Tasks

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Abstract

Targeting is a skill that involves the accurate projection of an object to a target; this requires accurate integration of visual information with spatial and motor skills. Targeting tasks demonstrate a consistent male advantage. Contrary to popular belief, this male advantage is not accounted for by participants' throwing experience or their size. The factors that mediate or account for the sex difference observed in targeting accuracy have not yet been identified. This dissertation addresses issues following from two prominent theories that attempt to explain this sex difference. The first theory proposes that the male advantage on targeting accuracy is due to the task's proxemic and/or motoric characteristics, whereas the second theory proposes that the sex difference in targeting accuracy is due to differential exposure to androgenic or estrogenic sex hormone concentrations. The first and second studies in this dissertation follow from the first theory, examining whether changing the motoric or proxemic characteristics of targeting tasks will mediate the sex difference. The third study is related to the second theory; it examines the relations among direct and indirect measures of prenatal and circulating sex hormone concentrations and targeting accuracy within samples of men and women. Collectively the results from studies 1 and 2 indicate that the proxemic and motoric characteristics are related to the sex difference on targeting tasks; specifically, targeting tasks must involve only fine motor movements and be performed in intrapersonal space in order for the male advantage to be negated. The results from study 3 indicate that men who were exposed to relatively high prenatal testosterone concentrations and continue to have relatively high circulating testosterone concentrations perform less accurately on targeting tasks than do all other groups of men. The results from study 3 also indicate that women exposed to relatively high prenatal testosterone concentrations target significantly more accurately than women that were exposed to relatively low prenatal testosterone concentrations. As well, the results showed that women who use oral contraceptives target significantly more accurately when they are not currently taking the exogenous estrogen supplements (menstrual phase) than

when they are taking the supplements (midluteal phase). These results are discussed in light of the two prominent theories explaining the sex difference in targeting accuracy. A synthesized theory is proposed, and directions for future research are discussed.

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List of Abbreviations

2D:4D ratio- The ratio between the length of the index and ring fingers

AFP- alpha-feto-protein

AMH- Anti-Müllerian Hormone

ANCOVA- Analysis of Covariance

ANOVA- Analysis of Variance

CAH- Congenital Adrenal Hyperplasia

DHT- Dihydrotestosterone

E- Estradiol

FSH- Follicle Stimulating Hormone

fMRI- functional magnetic resonance imaging

FRC- Finger Ridge Count

GP- Grooved Pegboard

LH- Luteinizing hormone

M- Mean

MRT- Mental Rotations Test

NoOC- Naturally cycling women

NSERC- Natural Sciences and Engineering Research Council

OC- women using oral contraceptives

P- Progesterone

PET- positron emission tomography

PP- Purdue Pegboard

SD- Standard Deviation

SEM- Standard Error of the Mean

SHBG- Sex-Hormone Binding Globulin

T- Testosterone

T/E ratio- the ratio between concentrations of testosterone and estradiol

TMS- Transcranial Magnetic Stimulation

Factors Mediating the Sex Difference Observed in Targeting Tasks

Targeting is a skill that requires the accurate aim and projection of an object to a target; the term can be used in reference to tasks that involve either a strictly aiming component (e.g., marksmanship), or both a throwing and aiming component (e.g., darts). This is a skill that consistently demonstrates a male advantage (Bard, Fleury, Carriere, & Bellec, 1981; Boyce, 1992; Butterfield & Loovis, 1993; Clark & Phillips, 1987; Davis, 1984; Epstein, 1980; Greenwood, Meeuwsen, & French, 1993; Hall & Kimura, 1995; Halverson, Roberton, & Langendorfer, 1982; Hines et al., 2003; Janowsky, Chavez, Zamboni, & Orwoll, 1998; Jardine & Martin, 1983; Lee, Fant, Life, Lipe, & Carter, 1978; Moore & Reeve, 1987; Moore, Reeve, & Pissanos, 1981; Morris, Williams, Atwater, & Wilmore, 1982; Patee, Frewen, & Beer, 1991; Sanders & Kadam, 2001; Sykes Tottenham & Saucier, 2004; Van Rossum, 1980; Watson & Kimura, 1989; Watson & Kimura, 1991). As derived from two prominent theories currently found within the targeting literature, this dissertation examined how the sex difference in targeting accuracy is influenced by the proxemic and motoric task characteristics, and how it is influenced by circulating and prenatal sex hormone concentrations. This dissertation begins by discussing the properties underlying the skill of targeting, and findings related to the sex difference observed on targeting tasks. The two prominent theories are then presented. Following this, the rationales for the current studies are discussed.

Due to the obvious and high profile involvement in games and sport, some people may regard targeting as a trivial skill that is of marginal importance. However, this preoccupation with Western cultural practice may miss the importance of targeting in the evolutionary prehistory of humans. Targeting has a long standing in human prehistory. Evidence suggests that our ancestors were targeting using wooden throwing spears over 400,000 years ago, that they may have been targeting using stone handaxes over 1,000,000 years ago, and likely using rocks as projectiles before the creation of such tools (Calvin, 1993; O'Brien, 1981; Thieme, 1997). Researchers believe that the emergence of accurate targeting ability was likely subject to both natural and sexual selection, as it

facilitates both defence and hunting activities (e.g., Calvin, 1982; Kolakowski & Malina, 1974; Watson, 2001). Some researchers and theorists credit the skill of targeting with additional evolutionary importance beyond hunting and defence, suggesting that it may have been the basis for the selection of enhanced spatial ability in males (e.g., Jardine & Martin, 1983; Kolakowski & Malina, 1974). Calvin (1982) further suggests that targeting may have facilitated the development of a left hemispheric specialization for precise motor timing and sequencing, which provided the neural rudiments for speech. Regardless, there is little doubt that targeting was an extremely important skill throughout our evolutionary heritage. Targeting continues to be a valued skill in many cultures in present day for hunting, athletic (professional and recreational), and law enforcement purposes.

Just as targeting is not a trivial skill, it is not a simple skill either. Although the movements associated with targeting tasks may be relatively simple to perform (especially when accuracy is not required), the neural processes underlying these movements are rather complex, requiring the integration of visual information with both spatial and motor skills. In order to target accurately one must visually identify and accurately analyse the spatial location of the target in relation to oneself; further, if it is a moving target, one must also accurately analyse its direction, speed, and trajectory. This visual and spatial information must be coordinated with the aiming action of the hands, arms, and body.

Targeting tasks can rely primarily on aim (e.g., marksmanship) or they can combine aiming with a throwing component (e.g., darts). Targeting tasks that involve only an aiming component are critically dependent upon body and arm stability and fine-motor control of the hand, wrist, and fingers. Targeting tasks that involve both a throwing and aiming component are more complicated and require the coordination of gross motor movements of the body and arms (giving the object momentum), with the fine motor control of the hands and fingers (releasing the object). Regardless of whether the targeting task involves a strictly aiming component or both an aiming and throwing component, one must correctly integrate visual and spatial information, and one must precisely time the release of

the projectile in order to achieve accuracy (for example, see: Hore, Watts, Martin, & Miller, 1995). Thus, targeting requires accurate visual and spatial analysis, and precise timing and coordination of the muscle groups involved in the motoric aspect of the specific targeting task.

The visual, spatial, and motor processes required for accurate targeting likely involve many brain regions. The spatial analyses required for accurate targeting would likely be more reliant upon the right hemisphere (Kimura, 1969; Saucier & Kimura, 1996), whereas the motor programming would likely be more reliant upon the left hemisphere (Kimura, 1977). The posterior parietal association cortex would presumably play a role in the integration of visual and proprioceptive information for the spatial analysis of where one is in relation to the target. As such, the posterior parietal association cortex, which is part of the dorsal visual stream, would be involved in determining *how* the motor component of targeting must be performed in order to achieve accuracy (Goodale, Milner, Jakobson, & Carey, 1991). The dorsolateral prefrontal association cortex receives information from the posterior parietal association cortex and uses this information in the planning of movement goals (Goldman-Rakic, 1987). The secondary motor cortex (which includes the supplementary motor area, the premotor cortex, and the cingulate motor areas) is governed by the association areas and is active before and during the execution of voluntary movements (Seitz, Stephan, & Binkofski, 2000), indicating that it is likely involved in planning and on-line monitoring of the movements. The primary motor cortex plans and executes the coordinated muscle movements that need to be taken in order to complete the planned movement. Finally, the basal ganglia and the cerebellum are involved in the smooth, coordinated execution of the targeting movement itself.

Men consistently outperform women on traditional targeting tasks such as ball or dart throwing (Bard et al., 1981; Boyce, 1992; Butterfield & Loovis, 1993; Clark & Phillips, 1987; Davis, 1984; Epstein, 1980; Greenwood et al., 1993; Hall & Kimura, 1995; Halverson et al., 1982; Hines et al., 2003; Janowsky et al., 1998; Jardine & Martin, 1983; Lee et al., 1978; Moore & Reeve, 1987; Moore et al.,

1981; Morris et al. , 1982; Patee et al. , 1991; Sanders & Kadam, 2001; Sykes Tottenham & Saucier, 2004; Van Rossum, 1980; Watson & Kimura, 1989; Watson & Kimura, 1991). Although men outperform women on most tasks involving spatial abilities (for review see: Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995) research has shown that the sex difference observed on targeting accuracy is much larger than the sex differences observed on most paper and pencil tasks of spatial abilities (except for mental rotations tasks, which demonstrate a large male advantage equal to that observed on targeting tasks; Kimura, 1999). Numerous studies have tried to elucidate the reason for this large sex difference. Contrary to popular belief, researchers have found that the sex difference in targeting accuracy is not explained by sex differences in previous sports and throwing experience (Hall & Kimura, 1995; Sykes Tottenham & Saucier, 2004; Watson & Kimura, 1989; Watson & Kimura, 1991), nor is it explained by sex differences in size and muscularity (Hall & Kimura, 1995; Lunn & Kimura, 1989). Correlations between targeting accuracy and performance on paper and pencil tasks of spatial ability are weak (e.g., Jardine & Martin, 1983; Kolakowski & Malina, 1974) or non-significant (Watson & Kimura, 1991). Thus it does not appear that spatial ability (or at least the types of spatial abilities assessed by paper and pencil measures) can wholly account for the sex difference in targeting accuracy. Further, research has shown that this sex difference in targeting accuracy does not appear to be due to a male advantage in calibrating aim over multiple trials; when multiple trials were given on a targeting task in which the visual scene was displaced by donning prism lenses, the accuracy of both men and women improved. However, no sex difference in the rate of improvement was observed (Sykes Tottenham & Saucier, 2004). The sex difference observed on targeting tasks also does not appear to be dependent upon: the orientation of the target (i.e., horizontal or vertical) (Jardine & Martin, 1983); the type of throw employed (i.e., under- or over-hand) or the type of projectile employed (i.e., ball or dart) (e.g., Hall & Kimura, 1995; Hines et al., 2003; Janowsky et al., 1998). At present, the factor(s) that are responsible for the male

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advantage on targeting accuracy are not known. There are, however, two prominent theories that address this issue.

Theory 1: Sex Differences in the Cerebral Organization of the Praxic System

Kimura and colleagues have put forth a theory proposing that the sex difference observed on targeting tasks is due to a sex difference in the cerebral organization of the praxic system (Chipman, Hampson, & Kimura, 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991). The theory proposes that sex differences in the organization of the praxic system facilitate male performance on targeting tasks due to their typical motoric and/or proxemic characteristics. This theory is based on Kimura's earlier research, which relied on patients with apraxia (1983, 1993).

Apraxia is a neurological disorder of motor programming that is characterized by the inability to produce purposeful movements, despite having the will and the physical ability to do so. Apraxia typically results from left hemisphere damage, but results in bilateral motor deficits (Kimura, 1977). The praxic system appears to be especially involved in complex sequenced movements that require minimal visual or tactile cues (Kimura, 1977; Kimura, 1993). To test for manual apraxia, patients may be asked to demonstrate how to use an object, or they may be required to imitate a series of unfamiliar movements (Kimura, 1987).

From her work with patients with apraxia, Kimura observed that there is a sex difference in the cerebral organization underlying praxic function in the left hemisphere; she noted that manual apraxia in women is most likely to result from lesions anterior to the central sulcus in the left hemisphere, whereas manual apraxia in men is more likely to result from lesions posterior to the central sulcus in the left hemisphere (1993). Following from this observation, Kimura and colleagues (Chipman et al., 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991) have proposed that the sex differences observed on targeting and fine motor tasks are due to an evolved and differential reliance on different regions of the left hemisphere for motor programming. Specifically, they propose that praxic function may have "migrated" more posteriorly in the left

hemisphere of the male brain over the course of evolution owing to selection pressures associated with hunting activities (especially targeting) (Chipman et al., 2002). Kimura and colleagues argue that this posteriorly located praxic system (which presumably includes the dorsal visual stream in the posterior parietal cortex; Goodale et al., 1991) is in close synaptic proximity to neural regions underlying visual and spatial processing, allowing for enhanced performance on motor tasks that are heavily reliant on the coordination of visual and spatial information (Chipman et al.). Additionally, Kimura and colleagues propose that the female praxic system "migrated" anteriorly in closer proximity to the motor cortex, presumably allowing for better fine motor control (Hall & Kimura, 1995; Kimura, 1983). This theory implies that the fine motor tasks that lead to this evolved sexual dimorphism in the praxic system required less input from the visual system compared to tasks directed at extrapersonal space. As well, the theory implies that men are more reliant on the visual system when performing motor tasks that are considered to be predominantly praxic in nature, and in fact this implication has been supported in a recent study by Chipman and colleagues.

Thus, the Kimura and colleagues' theory proposes that the sex differences that we see in present day on motor tasks are due to an evolved differential reliance on anterior or posterior cerebral regions for motor programming. Specifically, men typically have a posteriorly located motor programming system that allows them to excel on tasks involving "extrapersonal spatiomotor accuracy" (Watson & Kimura, 1991, p. 383). Conversely, women have an anteriorly located motor programming system that allows them to excel on fine motor tasks and tasks involving "intrapersonal motor accuracy" (Hall & Kimura, 1995; Watson & Kimura, 1991, p. 383).

Within this theory there are 2 distinct task characteristics that account for the sex differences observed in targeting accuracy and other motor tasks: proximity to the target (a spatial proxemic characteristic); and the type of motor movement required to complete the task (a motoric characteristic). This theory proposes that men excel at tasks directed at extrapersonal space (out of arm's reach, or as often defined in the literature, more than 150cm from the body),

whereas women excel at tasks performed in intrapersonal space (within arms reach) (Hall & Kimura, 1995). This theory also proposes that the female advantage on tasks performed in intrapersonal space may relate to their reliance on fine motor control. Tasks of fine motor control, such as the Purdue Pegboard (PP- female advantage; Tiffin, 1968), require very precise movements of small muscle groups (fingers), whereas tasks of predominantly gross motor control, such as intercepting projectiles and targeting (male advantage- Watson & Kimura, 1991), require large muscle groups and whole body movements (limbs and body). However, it should be noted that Kimura and colleagues' theory does not specifically mention that the male advantage on tasks directed at extrapersonal space should be related to a male advantage on gross motor movements. However, as male advantaged tasks directed at extrapersonal space typically entail both gross and fine motor movements, whereas female advantaged tasks performed in intrapersonal space typically only involve fine motor movements, this hypothesis is also plausible.

Given that there are differing neural regions underlying fine- and gross-motor movements and movements directed at intrapersonal or extrapersonal space, both task characteristics (i.e., proxemic and motoric) identified in this theory are plausible explanations for the resultant sex differences in motor skills. In primates, the lateral corticospinal tract is responsible for fine motor movements, whereas the lateral and ventral corticospinal tract, rubrospinal tract, and ventromedial tract are responsible for gross motor movements (Lawrence & Kuypers, 1968a & b). Evidence suggesting that there are differing neural regions underlying the analysis of intrapersonal and extrapersonal space comes from case studies of patients with apraxia and neglect that demonstrate dissociated impairments for these spatial domains. Researchers have described patients that have neglect for objects in extrapersonal space but not intrapersonal space (Anderson, 1993; Beschin & Robertson, 1997); as well, researchers have described patients that have neglect for objects in intrapersonal space but not extrapersonal space (Beschin & Robertson, 1997; Bisiach, Perani, Vallar, & Berti, 1986; Halligan & Marshall, 1991). Halsband and colleagues (2001) describe a

group of patients with apraxia (left parietal lobe damage) who were worse at imitating gestures on their own bodies than they were at imitating movement in reference to an external object. Further support for a dissociation between intrapersonal and extrapersonal space comes from a Positron Emission Tomography (PET) study performed by Weiss and colleagues (2000). Weiss and colleagues used PET to investigate the neural correlates associated with two tasks that were performed in intrapersonal space and extrapersonal space: a laser pointing task (i.e., fine motor targeting) and a laser line bisection task. They found that dorsal visuomotor processing areas were active when the tasks were performed in intrapersonal space, and ventral visuoperceptual processing areas were active when the tasks were performed in extrapersonal space. Thus, their study's results were congruent with the findings of the clinical case studies (discussed above) that have shown dissociations for processing information in near and far space. However, because Weiss's study only included male participants, it is unknown whether there was a sex difference in the regions of activation, which would have been predicted by Kimura and colleagues' theory.

Consistent with Kimura and colleagues' theory are the studies that have demonstrated a large and consistent male advantage for targeting tasks that are directed at extrapersonal space (Bard et al., 1981; Boyce, 1992; Butterfield & Loovis, 1993; Clark & Phillips, 1987; Davis, 1984; Epstein, 1980; Greenwood et al., 1993; Hall & Kimura, 1995; Halverson et al., 1982; Hines et al., 2003; Janowsky et al., 1998; Jardine & Martin, 1983; Lee et al., 1978; Moore & Reeve, 1987; Moore et al., 1981; Morris et al., 1982; Patee et al., 1991; Sanders & Kadam, 2001; Sykes Tottenham & Saucier, 2004; Van Rossum, 1980; Watson & Kimura, 1989; Watson & Kimura, 1991). Similarly, a female advantage on fine motor tasks that are performed in intrapersonal space, such as the PP and Grooved Pegboard (GP) have been repeatedly reported (Bornstein, 1985; Ruff & Parker, 1993; Schmidt, Oliveira, Rocha, & Abreu-Villaca, 2000; Spreen & Strauss, 1991; Tiffin, 1968). However, all of these studies confound proxemic and motoric requirements within the tasks of interest; thus, one cannot determine whether it is the proxemic or motoric characteristic of the tasks that affords the observed sex

difference. It is interesting to note that the fine motor tasks that demonstrated a female advantage do so even though they required accurate aiming ability (i.e. you must hit the hole to place the peg), which is remarkably similar to targeting tasks that demonstrate a male advantage.

In order to address whether it is the motoric or proxemic characteristics of a motor task that influence the resultant sex difference, one needs to examine tasks that do not utilize the typical pairing of proxemic-motoric task characteristics (i.e., intrapersonal→fine motor, extrapersonal→gross motor). Remarkably few studies have been conducted that did not utilize the typical pairing of proxemic-motoric task characteristics. For instance, Barral and Debu (2004) found a female advantage on a gross motor aiming task that was performed within intrapersonal space, in which participants had to physically contact targets with their hands. Similarly, Chipman and colleagues (2002) found a female advantage on the manual sequence box, which is a gross motor task performed in intrapersonal space; however, this task is unlike targeting in that there is no projectile to be aimed and it is minimally reliant on visual and spatial analysis. These findings of a female advantage on gross motor tasks partially contradicts Kimura and colleagues' theory; although it also partially supports their theory, as the tasks were performed in intrapersonal space. Boyce (1992) reported a male advantage on an extrapersonal targeting task requiring only fine motor movements (i.e., shooting a gun). However, this was only observed on the first and third of five trials and was inconsistent with Boyce's earlier findings and the findings of Kemnitz and colleagues (Boyce 1987, 1990; Kemnitz, Johnson, Merullo, & Rice, 2001). As such, these data are difficult to interpret, and cannot conclusively support or refute the theory proposed by Kimura and colleagues. It must be noted, however, that these studies were not specifically designed to test the theory put forth by Kimura and colleagues. Further, given that there was no object that had to be manipulated during the task (i.e., a projectile or a peg), one may question whether these tasks are comparable to the targeting tasks or pegboard tasks on which Kimura's theory was based.

Finally, although these studies (Barral & Debu, 2004; Boyce 1987, 1990, 1992; Kemnitz et al., 2001) are related to the theory proposed by Kimura and colleagues, they were conducted with vastly different tasks in different samples of participants. It is my position that in order to adequately address whether it is actually the motoric or proxemic characteristics of a motor task that influence the resultant sex difference, one must compare both gross- and fine-motor tasks performed both in intrapersonal and extrapersonal space within the same sample.

Theory 2: Sex Hormones and Targeting Accuracy

The second theory to be discussed that addresses the sex difference observed on targeting accuracy suggests that there is a relation between sex hormone concentrations (i.e., androgens and estrogens, specifically testosterone (T) and estradiol (E)) and targeting accuracy. Given that there is such a large sex difference on targeting tasks (previous studies have reported that the male advantage approaches a full standard deviation, or an effect size of 1.0 or greater; for review see Kimura, 1999) and given that researchers have previously found relations among sex hormones and other types of spatial and motor abilities (e.g., Hampson & Kimura, 1988; Kimura & Hampson, 1994) this is a testable and tenable hypothesis. A few studies have been conducted that have examined the relation between sex hormone concentrations and targeting accuracy (Hines et al., 2003; Janowsky et al., 1998; Sanders & Kadam, 2001; Saucier & Kimura, 1998). These studies have approached the question from one of two complementary time-points that can be used to examine this relation: investigations of the organizational effects of prenatal exposure to sex hormones; or investigations of the activational effects of circulating sex hormone concentrations.

Organizational effects of sex hormones on targeting accuracy. During prenatal development, exposure to sex hormones is essential for the development of the sexual phenotype. Prenatal hormone exposure effects are referred to as "organizational" effects because they create permanent changes in the developing body and brain, and their consequent behaviour (Goy & McEwen, 1980); these hormonally mediated sex differences in development have been observed in the brain and behaviour of humans and rodents (e.g., Arnold & Gorski, 1984; Collaer

& Hines, 1995; Williams & Meck, 1991). Prenatal androgens are responsible for masculinizing the phenotypic sex of the fetus: prenatal T and dihydrotestosterone (DHT) concentrations are necessary for the development of the male reproductive tracts and external genitalia; in females, it is the absence of anti-müllerian hormone (AMH) and the absence of T that allows for the development of the female reproductive tracts and external genitalia (for review see Breedlove & Hampson, 2002). Prenatal T also appears to masculinize the brain, however, it does so by being aromatized to estradiol; maternal estrogens do not appear to masculinize the fetus because they are bound by alpha-feto-protein (AFP) (for review see Breedlove & Hampson, 2002).

Researchers have previously demonstrated that there are relations among prenatal sex hormones concentrations and spatial abilities. Exposure to relatively high prenatal T concentrations appears to be associated with enhanced performance on spatial tasks in girls and women (Cole-Harding, Morstad, & Wilson, 1988; Finegan, Niccols, & Sitarenios, 1992; Grimshaw, Sitarenios, & Finegan, 1995; Hampson, Rovet, & Altmann, 1998; Kempel et al., 2005; Resnick, Berenbaum, Gottesman, & Bouchard, 1986). In boys and men it appears that performance on spatial tasks is impaired in individuals that were exposed to atypically low prenatal T concentrations (Hier & Crowley, 1982), as well as in individuals exposed to atypically high prenatal T concentrations (Hampson et al., 1998; Hines et al., 2003). Grimshaw and colleagues (1995) found that 7 year old boys who had been exposed to relatively low concentration of prenatal T outperformed boys exposed to relatively high concentrations of prenatal T on a mental rotations task. Collectively the results of studies suggest that spatial ability is facilitated by exposure to an optimal level of prenatal T concentrations; this optimal level appears to be within the low normal range for male fetuses, and the high normal range for female fetuses.

The relation between prenatal exposure to sex hormones and later targeting accuracy has been examined by a few researchers. For instance, Hines and colleagues (2003) compared the targeting accuracy of samples of men and women with congenital adrenal hyperplasia (CAH) with the targeting accuracy of

unaffected male and female relatives. CAH is a genetic disorder that causes an overproduction of androgens by the adrenal glands, resulting in the fetus being exposed to elevated T concentrations. When compared to unaffected women, women with CAH showed enhanced targeting accuracy on two targeting tasks: overhand ball throwing and overhand dart throwing (both directed at extrapersonal space); no significant differences on targeting accuracy were found between men with CAH and unaffected men. Their findings suggest that prenatal exposure to atypically high concentrations of T is associated with enhanced targeting accuracy in adolescent/adult women. However, prenatal exposure to atypically high concentrations of T does not appear to affect targeting accuracy in adolescent/adult men.

Sanders and Kadam (2001) examined the relation between targeting accuracy and finger ridge count (FRC) asymmetry in prepubescent boys and girls. FRC asymmetry is an indirect means of determining relative exposure to T prior to the 16th week of fetal development. FRC asymmetry is determined by counting the number of dermal ridges between the core and triradial points on fingerprints of the thumbs and little fingers; the total ridges for the thumb and little finger are totalled for each hand and are considered to demonstrate an asymmetry if one hand exceeds the total of the other by two or more ridges (see Holt, 1968). Prenatal exposure to relatively high concentrations of T is thought to be related to a FRC asymmetry that is greater on the right hand than the left hand, whereas prenatal exposure to relatively low concentrations of T is thought to be related to a leftward FRC asymmetry (Jamison, 1990; Kimura & Carson, 1995). Sanders and Kadam report that boys and girls with a rightward FRC asymmetry significantly outperformed their same sex counterparts who had leftward FRC asymmetries on an overhand dart throwing task (directed at extrapersonal space). They proposed that prenatal exposure to relatively high concentrations of T is associated with enhanced targeting accuracy in prepubescent boys and girls.

Activational effects of sex hormones on targeting accuracy. In adulthood, circulating sex hormones influence brain functioning, and consequent behaviour and body functions; these hormonal effects are referred to as "activational" effects

because they activate certain behaviours (Goy & McEwen, 1980). For instance, fluctuations in estradiol, progesterone, follicle stimulating hormone (FSH), and luteinizing hormone (LH) concentrations occur over the menstrual cycle to activate menstruation and ovulation (for review of relevant effects of the menstrual cycle on cognitive and motor performance see Hampson, 2002). Similarly, circulating sex hormone concentrations have been reported to have activational effects on spatial and motor abilities (for review see: Kimura & Hampson, 1994). For instance, performance on speeded motor tasks, such as the Manual Sequence Box and the Purdue Pegboard (both are female-favouring tasks), is enhanced in women when circulating concentrations of E are high (Hampson & Kimura, 1988; Saucier & Kimura, 1998), whereas performance on spatial tasks, such as the Rod-and-Frame test (male-favouring task), is impaired in women when circulating concentrations of E are high (Hampson & Kimura, 1988). Further, high circulating concentrations of T in women, and low circulating concentrations of T in men appear to be associated with enhanced performance on spatial tasks, such as the Vandenberg Mental Rotations Test (MRT; Moffat & Hampson, 1996), the Paper Folding Test (Gouchie & Kimura, 1991), and a navigation pointing task (Bell & Saucier, 2004). As such, there appears to be a curvilinear relationship between T concentrations and measures of spatial ability across the sexes.

Janowsky and colleagues (1998) used radioimmunoassay of serum hormone levels to examine the relation between circulating T and E concentrations and targeting accuracy on an overhand dart throwing task (directed at extrapersonal space). They found a negative correlation between circulating T concentrations and targeting accuracy in men. For women, circulating T and E concentrations were negatively correlated with performance of the non-dominant hand and positively correlated with performance of the dominant hand (Janowsky et al.). However, as Janowsky and colleagues themselves acknowledged, significant correlations in both the male and female samples were only found in the second of two testing sessions. Thus, further testing is required to confirm the relation between targeting accuracy and circulating T and E concentrations.

Saucier and Kimura (1998) used salivary radioimmunoassay to examine the relation between circulating E and progesterone (P) concentrations and targeting accuracy in women. Participants performed an underhand ball throwing task, directed at extrapersonal space. Their findings were similar to Janowsky and colleagues' (1998) findings, in that relatively low circulating E and P concentrations (menstrual phase) were associated with enhanced targeting accuracy of the non-dominant hand, whereas relatively high circulating E and P concentrations (midluteal phase) were associated with enhanced targeting accuracy of the dominant hand.

Discerning organizational and activational hormonal effects. As noted above, relations have been found between prenatal exposure to T and targeting accuracy in adulthood, and between circulating sex hormone concentrations and adult targeting accuracy. However, by only examining either the circulating or prenatal hormonal effects one can only achieve a partial account of the relation between sex hormone concentrations and targeting accuracy, as there may be a more complicated or interactive relation between these two types of hormonal measures. Although some researchers have found that indirect measures of exposure to prenatal sex hormone concentrations are associated with adult levels of circulating sex hormone concentrations in hormonally normal individuals (e.g., Manning, Scutt, Wilson, & Lewis-Jones, 1998; Manning, Trivers, Thornhill, & Singh, 2000), others have failed to find a significant association (e.g., Kempel et al., 2005). As such, the relation between prenatal exposure to relatively high (or low) T concentrations and circulating concentrations of T in adulthood is not well elucidated. Further, circulating concentrations of sex hormones are not stable in adulthood. Circulating concentrations of sex hormones fluctuate in adults: over the course of one's life (e.g., Burger, 1996; Harman, Metter, Tobin, Pearson, & Blackman, 2001); diurnally and seasonally in men (e.g., Dabbs, 1990a; Dabbs, 1990b); and diurnally and throughout the menstrual cycle in women (e.g., Dabbs, 1990a; Phillips & Sherwin, 1992). Further, circulating concentrations of sex hormones are commonly altered in adulthood by exogenous hormone supplementation (e.g., Brett & Reuben, 2003; Fisher & Boroditsky, 1998). Due to

the large confluence of factors that are difficult to substantiate in adulthood there is a strong likelihood that any association between prenatal and postnatal factors will be difficult, if not impossible, to discern without concentrated effort. As there is a possibility that circulating concentrations of sex hormones are not associated with prenatal concentrations of sex hormones, researchers should attempt to account for both the organizational and activational effects of sex hormones when examining sex differences in behaviour produced in adulthood.

Integration of the Two Theories

It must be recognized that Kimura and colleagues' theory that proposes that the sex difference in targeting accuracy is due to a sex difference in the cerebral organization of the praxic system is not mutually exclusive of the second theory. That is, there is no point at which Kimura and colleagues propose that cerebral organization is not influenced by sex hormone concentrations. Moreover, these theories can be integrated into one theory, and in fact such a synthesized theory was proposed by Hall and Kimura (1995). Hall and Kimura propose that the neural circuitry responsible for motor control that is directed at either intrapersonal or extrapersonal space is differentially affected by prenatal exposure to sex hormones. They also suggest that it may be the neural systems responsible for fine versus gross motor control that may be differentially affected by prenatal exposure to sex hormones. Although Hall and Kimura do not do so, their synthesized theory could be expanded to include a role for circulating sex hormones as well; with the relative concentrations of androgenic or estrogenic hormones exerting a sexually dimorphic activational effect on these underlying spatial-analysis and/or motoric neural systems.

Consistent with this assertion are the studies that have demonstrated a relation between circulating sex hormone concentrations and cognitive and motor abilities in men and women (for review see Kimura & Hampson, 1994). For instance, low levels of circulating T concentrations appear to be associated with enhanced targeting accuracy in men (Janowsky et al., 1998), whereas high levels of circulating E concentrations appear to be associated with enhanced fine motor skills in women (e.g., Hampson, 1990; Maki, Rich, & Rosenbaum, 2002). Thus,

organizational sex hormones may cause a sexually dimorphic organization of brain regions underlying gross- or fine- motor control, or the brain regions underlying motor control directed at intra- or extrapersonal space. These same brain regions are presumably acted upon by activational sex hormone concentrations, with high circulating E concentrations likely having a facilitating effect on intrapersonal and/or fine motor control in women, and high circulating T concentrations having an adverse effect on extrapersonal and/or gross motor control in men.

Current Studies

The research studies reviewed above demonstrate that the male advantage on targeting accuracy may be affected by factors such as: proximity to the task; the motoric characteristics of the task; and/or exposure to androgenic or estrogenic sex hormones. The purpose of this dissertation was to further investigate the role that these factors play in mediating the sex difference observed in targeting accuracy.

Study 1 was a preliminary experiment that was performed in order to investigate whether a male advantage could be found on a fine motor targeting task, and whether this advantage would be lessened or negated when the fine motor targeting task was performed in intrapersonal space. Study 2 further investigated the effects of the motoric and proxemic characteristics on the typically observed male advantage on targeting tasks. Study 2 was designed in a manner that would allow one to differentiate between the effects of the proxemic and motoric characteristics; that is, it included three targeting tasks that required gross- and fine-motor movements, and one targeting task that required strictly fine-motor movements, all of which were performed in both intrapersonal and extrapersonal space.

Very few studies have investigated the relation between circulating sex hormone concentrations and targeting accuracy, or the relation between prenatal exposure to sex hormones and targeting accuracy, and no study has investigated the relation among both prenatal and circulating sex hormone concentrations and targeting accuracy. As such, study 3 in this dissertation examined how estimated

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prenatal sex hormone concentrations and circulating T concentrations were related to targeting accuracy in men; and how estimated prenatal sex hormone concentrations, menstrual phase, and oral contraceptive use were related to targeting accuracy in women.

Study 1[1]

Running head: MEN ARE BETTER AT AIMING REGARDLESS OF
PROXIMITY

Men are More Accurate than Women at Aiming at Targets in Both
Near Space and Extrapersonal Space

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[1] Please note that each of the three studies in this dissertation have been formatted using the style
required by the journals that they have been submitted to, or published in.

Summary

Men excel at motor tasks requiring aiming[2] accuracy whereas women excel at different tasks requiring fine motor skill. However, these tasks are confounded with proximity to the body, as fine motor tasks are performed proximally and aiming tasks are directed at distal targets. As such, it is not known whether the male advantage on tasks requiring aiming accuracy is due to men having better aim, or due to the proximal domain in which the task is usually presented. Eighteen men (mean age=20.61 years, SD=3.01) and 20 women (mean age=18.70years, SD=0.86) participated in this study. Participants performed 2 tasks of extrapersonal aiming accuracy (>2 m from them), 2 tasks of aiming accuracy performed in near space (<1m from them), and a task of fine motor skill. Men outperformed women on both of the extrapersonal aiming tasks, and women outperformed men on the task of fine motor skill. However, a male advantage was observed for one of the aiming tasks performed in near space, suggesting that the male advantage for aiming accuracy does not result from proximity.

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[2] Note: The reviewers from Perceptual and Motor Skills required the use of the term aiming, in lieu of the term targeting (throughout study 1).

Men are More Accurate than Women at Aiming at Targets in Both

Near Space and Extrapersonal Space

Sex differences in performance can be observed in numerous motor tasks. For instance, men are more skilled than women at accurately hitting targets (e.g., Jardine & Martin, 1983; Watson & Kimura, 1989; Watson & Kimura, 1991; Sykes Tottenham & Saucier, 2004). Conversely, women perform tasks of fine motor skill more quickly and accurately than men (e.g., Tiffin, 1968; Bornstein, 1985; Spreen & Strauss, 1991; Nicholson & Kimura, 1996).

Sex differences in aiming accuracy have been suggested to result from differential sports experience, although two lines of evidence suggest that this is not the case. First, the sex difference in aiming accuracy appears in 4 year old children (Lunn & Kimura, 1989), presumably a time in which both sexes have similar levels of experience. Second, gay men have been found to be less accurate at throwing a ball at a target than heterosexual men, although differential experience with sports did not significantly account for this difference (Hall & Kimura, 1995). Additionally, when sports history is partialled out, a large sex effect on aiming accuracy still prevails (Watson & Kimura, 1991)

It has also been suggested that differences in size and muscularity can account for sex differences in motor skill (Peters, Servos, & Day, 1990). However, in the Lunn and Kimura study (1989), the children studied were of an age in which they were most likely to be the same size. Further, in the Hall and Kimura study (1995), heterosexual men were more accurate at hitting a target than both gay men and heterosexual women. The performance of gay men and heterosexual women was not significantly different, despite significant differences in size and muscularity between these two groups. Finally, there are numerous studies that have failed to find that finger size significantly affects fine motor skill (e.g., Hall & Kimura, 1995; Nicholson & Kimura, 1996).

However, one other difference between tasks of aiming accuracy and those of fine motor skill is where these tasks are performed. That is, tasks involving aiming accuracy require participants to hit targets that are distal to the body (extrapersonal space, >2 m from the body), whereas tasks of fine motor skill

require participants to interact with items proximal to the body (near space, <1m from the body). Thus, these sex differences in motor performance confound proximity with the type of skill (aiming accuracy vs. fine motor movements). Numerous studies have suggested that the male advantage observed in aiming accuracy may result from being distant from the target (e.g., Watson & Kimura, 1991; Hall & Kimura, 1995); however, this has not previously been examined. Additionally, a Positron Emission Tomography (PET) study by Weiss et al. (2000) has shown that pointing tasks performed in near and far space activate different brain regions in men (women were not examined). However, it is not yet known whether there are sex differences in brain activation when pointing at near and far space. As such, it appears that proximity may be an important factor potentially mediating sex differences observed on motor tasks of aiming accuracy and fine motor skill.

The purpose of this study was to investigate how proximity to the target affects performance on tasks requiring aiming accuracy. Participants performed numerous tasks requiring aiming accuracy in near and extrapersonal space, as well as performing a test of fine motor skill (i.e., Purdue Pegboard). The test of fine motor skill was included to ensure that our sample was representative of the population, as indicated by a female advantage on this task. In order to test aiming accuracy in near space, one novel task that measured aiming accuracy was developed. It was hypothesized that if proximity to the body predicts sex differences in motor skill, than a male advantage would be found for aiming tasks that occur in extrapersonal space, and a female advantage would be found for aiming tasks that occur in near space. Correlations were also examined to determine the degree of relatedness among the aiming tasks and the task measuring fine motor skill. It was expected that the extrapersonal projectile aiming task and laser aiming tasks performed in near and extrapersonal space would be significantly positively correlated with one another. However, as the computer aiming task utilized skills and measures that were quite different from the other aiming tasks, we did not expect them to be correlated. The task of fine motor skill was not expected to be correlated with the aiming tasks, given that

they measured two distinct types of activities (speeded fine motor versus fine and gross motor aim, respectively). Finally, we expected that performance of the right and left hands would be correlated for each of the motor tasks.

Methods

Participants

Eighteen men (mean age=20.61 years, SD=3.01) and 20 women (mean age=18.70years, SD=0.86) were recruited from the University of Saskatchewan introductory psychology participant pool. In order to keep the sample as congruent as possible, all participants were right-handed, as assessed by questionnaire (Elias, Bryden, & Bulman-Fleming, 1998). Participants were awarded one credit toward their research participation requirement.

Tasks and Procedure

All participants were tested individually by the same researcher. The testing session began by the participants providing informed consent, followed by the completion of a questionnaire containing questions regarding demographic information, computer experience (self-assessment, 7 point Likert-type scale), laterality and throwing experience or any other experiences that might account for differential skill between the hands. Following completion of the questionnaire, all participants performed 4 tasks assessing aiming accuracy and one task of fine motor skill. All tasks were performed with both the right and left hand, in a counterbalanced order. The order of the tasks was also counterbalanced among the participants.

Extrapersonal Projectile Aiming. Participants performed an extrapersonal aiming task (as in Saucier & Kimura, 1998). Participants threw a Velcro-covered ball that was 4.2 cm in diameter at a carpet covered target that was 285 cm from where they stood. The target was a 6.5 cm x 6.5 cm square, which was in the middle of a 145 cm x 145 cm carpet backdrop. The target was 147 cm above the floor.

Participants were required to throw the ball underhand at the target. Participants were given 5 practice trials, followed by 10 test trials for each hand. Each test trial was scored by measuring the distance between the ball and the

closest edge of the target. The average of these distances was the participants' score for each hand.

Extrapersonal Laser Aiming. Participants aimed a laser pointer at a target that was distant from them. Participants held the laser 230 cm from the target board. The centre of the target board was 158.5 cm above the floor. The target board was a 56 cm x 71 cm piece of cardboard with ten separate, randomly placed targets drawn on it. The targets were numbered circles, 4.2 cm in diameter.

Participants were required to aim the laser at the specified numbered target (as indicated by the researcher). Participants were instructed to 'aim, click, and release the button' on the laser pointer, so as to keep each trial separate, instead of creating one continuous path. The laser point was only visible during the 'clicking of the button,' thus not allowing for any online or offline correction during the trial. Participants were given 10 practice trials, followed by 10 test trials for each hand. Participants' performance on this task was recorded using a video camera. Each test trial was scored by measuring the distance between the place where the laser first appeared, and the closest edge of the target. The average of these distances was the participants' score for each hand.

Laser Aiming in Near Space. Participants aimed a laser pointer at a target that was close to them. In order to keep participants from holding their hand too close to the target, participants were required to rest their hand, which held the laser pointer, on a stand that was 88 cm from the target board. The centre of the target board was 138 cm above the floor. The target board was a 21.5 cm x 28 cm piece of cardboard with ten separate, randomly placed targets drawn on it. The targets were lettered circles, 1.6 cm in diameter.

Participants were required to aim the laser at the specified lettered target (as indicated by the researcher). Participants were instructed to 'aim, click, and release the button' on the laser pointer, so as to keep each trial separate, instead of creating one continuous path. The laser point was only visible during the 'clicking of the button,' thus not allowing for any online or offline correction during the trial. Participants were given 10 practice trials, followed by 10 test trials for each hand. Participants' performance on this task was recorded using a video camera.

Each test trial was scored by measuring the distance between the place where the laser first appeared, and the closest edge of the target. The average of these distances was the participants' score for each hand.

Computer Aiming. Participants performed a computerized aiming task in near space (also known as 'the multidirectional point-select task,' described in *International Organization for Standardization*, 1998, 9241-9). A target was displayed on the computer screen (19 inch monitor; Pentium III computer, 450 Mhz). Participants sat 60 cm away from the monitor. Participants were instructed to move the cursor to the target as quickly and accurately as possible, and click on it using a mouse. The computer screen displayed 24 circles that were 1.5 cm in diameter. These circles were arranged in a circle 14.5 cm in diameter. The target circle was a different colour than the others (green instead of white). Once the target circle was successfully selected, a different circle would become the target. If the target was not successfully selected the participant would have to try to select it again, until successfully completing the trial. Only one circle was the target at any one time, and the target selection alternated from side to side among the 24 circles until all 24 circles had been used as targets. Each test trial was scored using the average path length the cursor traveled between targets, the average number of errors, and the total time to complete the task, for each hand.

Purdue Pegboard. The Purdue Pegboard was used as a test of fine motor skill, at which women typically score higher than men (Tiffin, 1968). Participants were required to pick-up pegs one at a time from the cup in the board, and then place them in the holes in the board one at a time. This was done until all of the holes were filled. The time to complete the task was recorded. Each participant performed three trials: one with the right hand, one with the left hand, and one with both hands at the same time. Participants were scored on how quickly they could complete the task.

<div align="center">Results</div>

Extrapersonal Projectile Aiming Task.

A repeated-measures ANOVA was performed for the *extrapersonal projectile aiming* task. For the analysis, the accuracy of participants'

extrapersonal aiming was analyzed using sex (male, female) as the between-subjects measure and hand (right, left) as a within-subject measure. The dependent measure was the average distance between the first 'hit' point and the closest edge of the target. Initially an ANCOVA was run, using throwing experience as the covariate, however this covariate was not significant ($F(1, 35)=0.07$, $p=0.80$, $\eta^2=0.02$), and as such only the ANOVAs are reported. The reliability of this task was determined using Cronbach's Alpha.

As predicted, the *extrapersonal projectile aiming* task exhibited a significant main effect of sex, $F(1, 36)=3.62$, $p=0.03$, $\eta^2=0.09$, with men outperforming women (Table 1). There was also a significant main effect of hand used to aim, $F(1, 36)=19.12$, $p<0.001$, $\eta^2=0.35$, with the right hand outperforming the left hand (right hand average deviation from centre $M=8.70$ cm, $SD=4.33$; left hand average deviation from centre $M=11.88$ cm, $SD=5.08$). For the *extrapersonal projectile aiming* task, the interaction between sex and hand did not reach significance, $F(1, 36)=0.50$, $p=0.46$, $\eta^2=0.01$. The *extrapersonal projectile aiming* task was found to be reliable ($\alpha=0.75$).

Extrapersonal and Near Laser Aiming Tasks.

A repeated-measures ANOVA was performed in order to examine whether there was a sex or hand difference in participants' accuracy on either the near or extrapersonal laser aiming task, and to investigate the association between these two tasks. For the analysis, the accuracy of participants' aiming was analyzed using proximity (near, extrapersonal) and hand (right, left) as a within-subject measures, and sex (male, female) as the between-subjects measure. The dependent measure was the average distance between the first 'hit' point and the closest edge of the target. Initially an ANCOVA was run, using throwing experience as the covariate, however this covariate was not significant ($F(1, 35)=0.10$, $p=0.76$, $\eta^2=0.003$), and as such only the ANOVAs are reported. The reliability of this task was determined using Cronbach's Alpha.

The *laser aiming* tasks exhibited a significant main effect of sex, $F(1, 36)=11.19$, $p=0.002$, $\eta^2=0.24$, with men outperforming women (Table 1). Not surprisingly the laser aiming tasks also exhibited a significant main effect of

proximity, $F(1, 36)=80.73$, $p<0.001$, $\eta^2=0.69$, with performance in near space being more accurate than performance in extrapersonal space (M=3.05cm, SD=1.31; and M=11.31cm, SD=6.21, respectively). The interaction between sex and proximity was also significant, $F(1, 36)=6.30$, $p=0.02$, $\eta^2=0.15$ (male near : M=2.55cm, SD=0.83; male extrapersonal: M= 8.42cm, SD=6.20; female near : M=3.51cm, SD=1.51; female extrapersonal: M=13.92cm, SD=5.06). Post hocs indicate that there was a significant male advantage in both near and extrapersonal space, but that the effect was greater in extrapersonal space, $F(1, 36)=5.65$, p=0.02, η^2=0.14, and $F(1, 36)=9.06$, p=0.005, η^2=0.20, respectively. There was no main effect of hand, $F(1, 36)=1.22$, p=0.28, η^2=0.03. Further, there were no significant interactions between: hand x sex, hand x proximity, and hand x proximity x sex, $F(1, 36)=2.58$, p=0.12, η^2=0.07, $F(1, 36)=0.31$, p=0.58, η^2<0.01, and $F(1, 36)=2.49$, p=0.12, η^2=0.07, respectively. The *near laser aiming* task and the *extrapersonal laser aiming* task were found to be reliable (α=0.78 and α=0.84, respectively).

  Computer Aiming Task.

Three repeated-measures ANOVAs were performed for the *computer aiming* task, analyzing time, missed targets and pathlength, respectively. For each analysis, the accuracy of the participants' aiming in near space was analyzed, using sex (male, female) as the between-subjects measure and hand (right, left) as a within-subject measure. The dependent measures were the average path length, average number of missed targets, and total time to complete the task. Initially ANCOVAs were run using computer experience as the covariate, however this covariate was not significant for any of the analyses (time: $F(1, 35)=0.08$, p=0.78, η^2=0.002; missed targets: $F(1, 35)=0.67$, p=0.42, η^2=0.02; pathlength: $F(1, 35)=0.001$, p=0.99, η^2=0.001), and as such ANOVAs are reported. The reliability of these tasks was determined using Cronbach's Alpha.

The *computer aiming* task exhibited a main effect of hand used to aim for the total time per target to complete the task, $F(1, 36)=269.35$, $p<0.001$, η^2=0.88, with the right hand outperforming the left (right M=22.54 sec, SD=2.29; left

M=35.95 sec, *SD*=5.15). There were no other significant effects observed for the average time per target. For the average number of missed targets, there was also a main effect of hand used to aim, $F(1, 36)=40.19$, $p<0.001$, $\eta^2=0.53$, with the right hand outperforming the left hand (right *M*=0.05 errors, *SD*=0.05; left *M*=0.12 errors, *SD*=0.08). There were no other significant effects observed for the average number of missed targets.

For the average path length, there was also a main effect of hand used to aim, $F(1, 36)=147.15$, $p<0.001$, $\eta^2=0.80$, with the right hand outperforming the left hand (right *M*=434.06 mm, *SD*=40.86; left *M*=590.95 mm, *SD*=87.88). However, there was also a significant interaction between hand used to aim and sex, $F(1, 36)=6.24$, $p=0.02$, $\eta^2=0.15$ (male right: *M*=444.89mm, *SD*=47.89; male left: *M*= 568.14mm, *SD*=71.48; female right: *M*=424.3mm, *SD*=31.43; female left: *M*=611.48mm, *SD*=97.63). Post hocs indicate that although the right hand required significantly shorter path lengths ($p<0.05$), that women required shorter path lengths than men with their right hand, although this difference did not reach significance ($p>0.05$). This pattern was reversed for the left hand, as men required significantly shorter path lengths than did women ($p<0.05$). There were no other significant effects observed for the *computer aiming* task. The *computer aiming* task was found to be reliable for time per target ($\alpha=0.81$), and path length ($\alpha=0.79$). The *computer aiming* task was not found to be reliable for missed targets ($\alpha=0.36$), although there were so few missed targets (averaging <1 per person) that this measure may not be meaningful.

Purdue Pegboard.

A repeated-measures ANOVA was performed for the *Purdue Pegboard*, with the total time to complete the task as the dependent measure, and sex (male, female) as the between-subjects independent measure, and hand used to place the pegs in the holes (right, left, both) as a within-subject independent measure. The reliability of this task was determined using Cronbach's Alpha.

As predicted, the *Purdue Pegboard* exhibited a significant main effect of sex, $F(1, 36)=19.98$, $p<0.001$, $\eta^2=0.36$, with women outperforming men (Table 1). There was also a significant main effect of hand used to place the pegs, $F(1,$

36)=145.46, $p<0.001$, $\eta^2=0.80$, with the right hand outperforming the left hand and both hands (right $M=51.17$ sec, $SD=6.09$; left $M=57.54$ sec, $SD=6.78$; both $M=66.18$ sec, $SD=6.61$). The interaction between sex and hand did not reach significance, $F(1, 36)=0.07$, $p=0.94$, $\eta^2<0.001$. Performance on the *Purdue Pegboard* of the left hand, right hand, and both hands combined was found to be reliable ($\alpha=0.85$).

Correlations among the Aiming Tasks.

A Pearson Correlation was performed to determine the degree of relatedness among the aiming tasks and the task of fine motor skill. Correlations among the extrapersonal projectile aiming task, the computer aiming task, the near and extrapersonal laser aiming tasks, and the Purdue Pegboard were examined. Because the performance of the right and left hand was significantly correlated for each of the motor tasks (extrapersonal projectile: $r=0.56$, $p<0.001$; extrapersonal laser: $r=0.59$, $p<0.001$; near laser: $r=0.65$, $p<0.001$; computer path length: $r=0.25$, $p=0.05$; Purdue Pegboard: $r=0.60$, $p<0.001$), results of the right and left hand were averaged for each aiming task in order to simplify the cross-task comparison.

Significant positive correlations were found among the extrapersonal projectile aiming task and the near and extrapersonal laser aiming tasks (Table 2). As was expected, performance on the computer aiming task and on the Purdue Pegboard did not correlate with performance on the other aiming tasks (Table 2).

Discussion

As predicted, men were more accurate than women on both of the extrapersonal aiming tasks. Men were also significantly more accurate at the near laser aiming task and there was a simple main effect of sex favouring men on the computer aiming task (for left hand only). As expected, women performed significantly better than men on the Purdue Pegboard, indicating that our sample was comparable to other reports. As expected, the near and extrapersonal laser aiming tasks and the extrapersonal projectile aiming task were significantly correlated, but the Purdue Pegboard and the computer aiming tasks were not. Collectively the results suggest that the male advantage for aiming accuracy is not

related to proximity to the body because the male advantage emerges in both extrapersonal and near space. However, the interaction between sex and proximity found on the near space and extrapersonal laser aiming tasks indicates that although proximity mediates the sex difference (with near space showing a smaller effect than extrapersonal space), it does not negate it.

For the computer aiming task, there was only a simple main effect of sex for performance with the left hand (path length only), which may at first appear to be problematic. However, as the computer aiming task required the use of a mouse, it is likely the case that there was no simple main effect of sex for the right hand as most university students are highly skilled at using a mouse with their dominant right hand. This position is further supported by the limited number of errors made by participants, which occurred, on average, less than once per trial. As sex differences are enhanced by difficulty (e.g. Collins & Kimura, 1997), and as completion of the computer aiming task was more difficult for the left hand than the right hand (as indicated by significantly worse performance with the left hand), it is likely that the sex difference on this task only emerged when difficulty was increased by having participants perform it with their left hand.

The significant correlations among the performance on the extrapersonal projectile aiming task and the near and extrapersonal laser aiming tasks indicate that there was a high degree of relatedness among the tasks, despite large differences in the way these tasks were performed. Specifically, the extrapersonal projectile aiming task required gross ballistic motor movements as well as fine motor movements (i.e., at the time of ball release), whereas the laser aiming tasks only required fine motor movements. As such, it does not appear that the male advantage on extrapersonal aiming tasks and the female advantage on tasks of fine motor skill in near space are resultant from either proximity to the task, or the type of motor movement required. Rather it appears that the requirements of the tasks themselves mediate the sex differences observed on them: men are better at accurately aiming, whereas women are better at performing tasks of speeded fine motor skill (e.g., Purdue Pegboard).

The results of this study appear to indicate that the male advantage found in aiming accuracy is not simply due to proximity, as a male advantage was found on both near and extrapersonal aiming tasks. Additionally, it appears that the male advantage on aiming can be found across different types of aiming tasks, requiring quite different motor movements. As such, this study was unable to answer the question of what causes the male advantage found on aiming tasks, but we did rule out the possibility that proximity is a confounding factor in the observed sex difference. Further research is required examining other factors that could potentially mediate the sex differences observed in aiming.

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Table 1

Significant Male Advantage on the Aiming Tasks, and Significant Female

Advantage on the Fine Motor Task

Task	F(df), p (1-tailed)	Male Mean (SD)	Female Mean (SD)
Extrapersonal Projectile*	3.62(1,36), 0.03	8.98cm (3.91)	11.46cm (4.09)
Laser	11.19(1,36), 0.002	5.48cm (5.28)	8.71cm (6.43)
Purdue Pegboard	19.98(1,36), 0.001	57.89sec (6.09)	51.18sec (3.73)

*on all tasks a high score indicates poorer performance than a low score

Table 2

Intercorrelations Among the Aiming Tasks (n=38)

Aiming Tasks	1	2	3	4	5
1. Extrapersonal Projectile	-	0.45**	0.30*	0.06	-0.08
2. Extrapersonal Laser		-	0.29*	0.06	-0.23
3. Near Laser			-	0.19	-0.10
4. Computer (path length)				-	-0.21
5. Purdue Pegboard					-

* significant at $p<0.05$ (1-tailed)

** significant at $p<0.01$ (1-tailed)

Rationale for Study 2

Study 1 demonstrated that a male advantage was observed on a fine motor targeting task (i.e., laser targeting) regardless of whether it was performed in near or extrapersonal space; although, proximity significantly reduced the male advantage in near space, but did not negate it. In Study 1, the laser targeting tasks were performed in *near* (88cm) and extrapersonal space (230cm). However, as pointed out by a reviewer, there may have been some participants who were not within arms' reach for the near space targeting task. This becomes important, as it is on motor tasks performed in *intrapersonal* space (within arms' reach) that we see a female advantage (e.g., Barral & Debu, 2004; Bornstein, 1985; Spreen & Strauss, 1991; Tiffin, 1968). In study 1, I wanted to keep the distance between each participant and the target consistent, so as to keep the index of difficulty similar between the laser targeting tasks. However, in keeping the distance on the near targeting task the same between participants I may have reduced the likelihood that I would find a female advantage, as the task may not have actually been performed within the subjectively defined domain of intrapersonal space. As such, Study 2 required participants to complete targeting tasks in both extrapersonal space and the subjectively defined domain of intrapersonal space. This definition of intrapersonal space was necessarily variable between participants, as it was based upon the actual arm-length of participants. Further, in Study 1 the laser targeting task performed in near space required participants to support their targeting hand on a hand-rest in order to control their distance from the target, although no hand-rest was used for the extrapersonal version of the laser targeting task. This difference in methodology and potential effects on the performance of the participants in the near space version of the task may have resulted in the significant sex by proximity interaction. Thus, we no longer required participants to use a hand-rest for the intrapersonal tasks performed in study 2. Participants were, however, visually monitored to ensure that they were maintaining a constant distance from the target while performing the intrapersonal tasks in study 2. Study 2 also improved upon the methodology of Study 1 by utilizing four targeting tasks (3 of which required gross and fine motor

movements, while the remaining task required only fine motor movements), which were all performed in both intrapersonal and extrapersonal space. Unlike Study 1, in which only cross-task comparisons were performed, the design of Study 2 allowed me to compare the effects of proximity within the same targeting tasks. Additionally, by examining both gross and fine motor targeting tasks performed in both intrapersonal and extrapersonal space in Study 2 I was able to differentiate between the proxemic and motoric effects that may have lessened the sex difference on the fine motor targeting task performed in near space in Study 1. Finally, I further attempted to improve on the methodology of Study 2 by including a more detailed throwing and aiming experience questionnaire, as opposed to the throwing experience questionnaire that was used in study 1, which did not produce a significant covariate for throwing accuracy. Thus, Study 2 was performed in an attempt to further clarify the effects that proximity and movement type have on the sex difference typically observed on targeting tasks.

Running head: MALE ADVANTAGE FOR TARGETING NEGATED

Proxemic and Motoric Task Characteristics Interact to Negate the Male

Advantage on Targeting Accuracy

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Abstract

We examined whether the male advantage that is typically observed on targeting tasks could be mediated by changing proximity to the target or by changing the type of movement required to complete the task. To investigate these factors, we designed four targeting tasks that were performed in both intrapersonal (within arms reach) and extrapersonal space (>150 cm from the body) that required either predominantly gross or fine motor movements. We found a significant male advantage on all targeting tasks (N=60, 30 women). However, proximity significantly mediated the sex difference on the fine motor targeting task, suggesting that both factors may collectively influence sex differences in motor abilities. Thus, our data are consistent with the theory proposed by Kimura and colleagues that suggests that the sex differences observed on targeting and fine motor tasks is due to a sexual dimorphism in the organization of the motor programming system resulting in men excelling at extrapersonal motor tasks, and women excelling at tasks that require fine motor control (Chipman, Hampson, & Kimura, 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991).

Proxemic and Motoric Task Characteristics Interact to Negate the Male
Advantage on Targeting Accuracy

Sex differences can be observed on many motor and cognitive tasks (for review see: Benbow, 1988; Hyde & Linn, 1988; Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). Previous research has demonstrated that there are consistent sex differences on tasks involving two types of motor skills: gross motor skill (e.g., targeting and interception accuracy) and fine motor skill (e.g., completion of the Purdue or Grooved pegboard tasks). The direction of the sex differences on these motor skills is opposite; that is, men outperform women on targeting and interception tasks (Jardine & Martin, 1983; Sykes Tottenham & Saucier, 2004; Watson & Kimura, 1989; Watson & Kimura, 1991), whereas women outperform men on fine motor tasks such as the Purdue Pegboard (PP) and the Grooved Pegboard (GP) (Bornstein, 1985; Ruff & Parker, 1993; Schmidt, Oliveira, Rocha, & Abreu-Villaca, 2000; Spreen & Strauss, 1991; Tiffin, 1968). It is of interest to note that these opposing sex differences on targeting accuracy and pegboard completion are present despite the fact that successful completion of both types of tasks requires accurate aiming ability (targeting- accurate projection of an object to a target; PP/GP- accurate placement of pegs in the appropriate target holes).

Researchers have attempted to elucidate the cause of the sex difference observed on targeting and fine motor tasks, and have found that it is not simply a result of differences in size or muscularity (Clark & Phillips, 1987; Hall & Kimura, 1995; Lunn & Kimura, 1989; Nicholson & Kimura, 1996; Watson & Kimura, 1989). Further, studies have shown that the sex difference in targeting accuracy is not a result of: differences in past sports and throwing experience (Butterfield & Loovis, 1993; Hall & Kimura; Watson & Kimura, 1989; Watson & Kimura, 1991), differences in balance (Butterfield & Loovis), or differences in calibration ability (Sykes Tottenham & Saucier, 2004). Nor is the sex difference due to the orientation of the target (i.e., horizontal or vertical) (Jardine & Martin, 1983). The current study is based on a theory proposed by Kimura and colleagues, which proposes that the sex differences observed on targeting and fine motor

tasks is due to a sexual dimorphism in the organization of the motor programming system that enables men to excel at extrapersonal motor tasks, and women to excel at tasks requiring fine motor control (Chipman, Hampson, & Kimura, 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991).

In 1983 Kimura reported data on the incidence of aphasia and manual apraxia within a sample of right-handed patients who had left hemisphere lesions. Within this sample, there was a sub-sample of patients who had damage localized either anterior or posterior to the central sulcus. Kimura observed that aphasia and apraxia in female patients resulted from anterior lesions more often than posterior lesions, whereas male patients had an equal or reverse pattern wherein they were more likely to experience aphasia and apraxia following posterior damage to the left hemisphere. From this observation, Kimura and colleagues have suggested that two unique task characteristics (proximity and movement type) may be differentially facilitated by this organization, which in turn accounts for the sex differences observed on tasks such as the PP or targeting (Chipman et al., 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991). They suggest that in males, the praxic system migrated posteriorly over the course of evolution owing to selection pressures associated with typical male activities, such as hunting. They propose that this posteriorly located praxic system in which "visual input is synaptically close" (Kimura, 1993, p. 157), allows for better integration of visual information with the motor command. This in turn allows men to excel on motor tasks directed at extrapersonal space, as they critically require visual information. Alternatively, the female praxic system may have migrated anteriorly to be in close proximity to the motor cortex, owing to selection pressures associated with typical female activities involving fine motor skill that are less reliant on visual information, such as weaving or knitting. Kimura and colleagues propose that the sex differences observed on targeting and fine motor tasks in the current day are due to an evolved differential reliance on anterior or posterior regions of the left hemisphere for motor programming, which allows men to excel on extrapersonal spatiomotor tasks and women to excel on tasks requiring fine motor skill.

However, Kimura and colleagues' theory proposes two separate task characteristics to account for sex differences in motoric skill: 1) proximity to the task, and 2) the type of movement required to complete the task (fine versus gross motor movements). That is, the PP is performed in intrapersonal space (within arm's reach) and demonstrates a female advantage; targeting is directed at extrapersonal space (>150cm from the body) and demonstrates a male advantage. However proximity to the task is confounded with motoric skill, as the PP requires fine motor skill and demonstrates a female advantage; whereas targeting requires both gross and fine motor skill and demonstrates a male advantage.

The purpose of the current study is to investigate whether the sex difference typically observed on targeting tasks can be mediated by: 1) manipulating the proxemic domain in which the task is performed, or 2) changing the type of motor movement required to complete the task. Traditionally, targeting tasks that demonstrate a male advantage are directed at extrapersonal space and involve predominantly gross motor movements. As such, the current investigation required male and female participants to complete four targeting tasks in both intrapersonal and extrapersonal space; three of these targeting tasks required predominantly gross motor movements (an underhand projectile task, an overhand projectile task, and a rolling targeting task) and the fourth required fine motor movements (a laser targeting task). The extrapersonal versions of the projectile targeting tasks have been used previously in studies investigating targeting accuracy (e.g., Hall & Kimura, 1995; Saucier & Kimura, 1998; Sykes Tottenham & Saucier, 2004). The rolling targeting task was a novel task that was included to see if the male advantage would generalize to a new type of targeting that only allowed for horizontal (i.e., right/left) errors, but not vertical (i.e. up/down) errors. The laser targeting task was included in the test battery for two reasons: 1) It required accurate movement, aiming, and timing in order to 'hit' a target (similar to traditional measures of targeting that use projectiles); and 2) It required only fine motor movements for accurate targeting. Thus, the inclusion of the laser targeting task performed in both intrapersonal and extrapersonal space can allow for investigation into whether the sex difference in targeting is due to

proximity (which the other three targeting tasks also address), or whether it is due to a male advantage for controlling the gross motor movements involved in traditional measures of targeting that utilize projectiles. Further, it should be noted that the movements required to complete each of the targeting tasks were quite different from one another, allowing us to investigate whether the male advantage is due to an overall skill advantage for targeting, or whether it is due to biomechanical factors that affect performance of the task.

The current study is an extension of a study conducted previously, which also examined whether proximity influenced the sex difference observed on targeting tasks (Sykes Tottenham, Saucier, Elias, & Gutwin, 2005). The previous study involved an underhand projectile targeting task performed in extrapersonal space, a computer targeting task performed in near space, and a laser targeting task that was performed in both near and extrapersonal space. The typical male advantage was found on all of the targeting tasks (albeit only in the left hand for the computer targeting task). However, it was found that proximity significantly reduced the male advantage on the laser targeting task when it was performed close to the body. As such, although proximity may have influenced the sex difference observed on the laser targeting task, it did not negate it.

There were, however, issues in this previous study that the current study intends to address. For instance, in the previous study participants performed the laser targeting task at a set distance from the target (88cm); although this is likely within arms reach (i.e., within intrapersonal space) the set distance is problematic due to known sex differences in arm length between men and women. That is, for some women 88 cm may have been at the end of, or beyond, intrapersonal space, whereas fewer men would have likely encountered such a problem. As tasks of motor skill that demonstrate a female advantage are performed in intrapersonal space (within arms' reach), performing the laser targeting task at 88 cm from the body may have reduced the potential for women to demonstrate an advantage for intrapersonal motor tasks. As such, the current study required participants to perform the targeting tasks within their own subjectively defined intrapersonal spatial domain. Further, because the only task that was performed in both near

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and extrapersonal space in the previous study was a fine motor task, one can not determine whether results would be similar for predominantly gross motor targeting tasks performed in both proxemic domains. As such, to differentiate between the effects of proximity and movement type, the current study used four of the same targeting tasks (three of which involved predominantly gross motor movements) performed in both intrapersonal and extrapersonal space.

Based on the results of previous studies (Sykes Tottenham et al., 2005; Jardine & Martin, 1983; Sykes Tottenham & Saucier, 2004; Watson & Kimura, 1989; Watson & Kimura, 1991), we expected to find a male advantage for the four targeting tasks performed in extrapersonal space. We also expected that the male advantage would be reduced or obviated for the four targeting tasks performed in intrapersonal space. Further, we predicted that the laser targeting task would be the most likely to show a reduced male advantage in intrapersonal space, as it was the only fine motor targeting task.

To ensure that our sample was comparable to other studies, we expected to see the following results for the tasks that typically demonstrate sex differences: the PP (Tiffin, 1968), a fine motor task that exhibits a female advantage; the Mental Rotations Test (MRT) (Vandenberg & Kuse, 1978), a spatial task that typically exhibits a male advantage; and, of course, the traditional targeting tasks (i.e., the extrapersonal projectile targeting tasks) that typically exhibit a male advantage. Correlations amongst the targeting tasks, the PP, and the MRT were also examined in order to determine the interrelatedness of these tasks. We expected to find positive correlations among the targeting tasks, as they all involve the same underlying requirement of accurate aim. We also expected to find positive correlations among the tasks requiring fine motor control (i.e., the PP and both laser targeting tasks). Based on previous reports (e.g., Saucier & Kimura, 1998), we did not expect to find significant correlations among the MRT and the targeting tasks.

Method

Participants

  Thirty men and 30 women took part in this study (mean age: men=19.6 years, SD=1.81; women=19.3 years, SD=3.49). Participants were recruited through a participant pool in the Department of Psychology at the University of Saskatchewan. All participants were right-handed, as assessed by questionnaire (Elias, Bryden, & Bulman-Fleming, 1998), and had normal or corrected to normal vision. Participants were compensated for their participation.

Tasks and Measures

  Extrapersonal projectile targeting. Participants performed an extrapersonal projectile targeting task, as described in Sykes Tottenham et al. (2005). Participants threw a Velcro-covered ball (4.2 cm in diameter) at a carpet covered target (6.5 cm x 6.5 cm square) that was 285 cm from where they stood. The target was in the middle of a 145 cm x 145 cm carpet backdrop, which had a 10 cm x 10 cm grid marked on it to allow for ease of scoring. The target was 147 cm above the floor.

  Participants were required to complete two separate sets of trials in which they threw the ball at the target: one set of trials required an overhand throw, the other set of trials required an underhand throw. Participants were given three practice trials, followed by ten test trials, for each hand and for each type of throw. The position where the ball landed on each test trial was recorded. Scoring was completed by measuring the distance between the closest edge of the target and where the ball hit. The average of these distances was the participants' score for each hand and each type of throw.

  Intrapersonal projectile targeting. The equipment used in the intrapersonal projectile targeting tasks was similar to the equipment used in the extrapersonal projectile targeting tasks, however, the size of the ball and the size of the target were proportionately smaller. This was done so as to keep the index of difficulty between the intrapersonal and extrapersonal projectile targeting tasks comparable. Because the average human arm is approximately 79 cm long (Ross, Carr, & Carter, 2000), and because participants were standing at arms' length

from the target, we estimated that the average distance between the participant and the intrapersonal target would be 79 cm. Using this estimated distance, we proportionately scaled down the size of the ball and target used in the extrapersonal projectile targeting task, for the intrapersonal projectile targeting task. Thus, to ensure that this was not a confound, each participant's arm length was measured and was used as a covariate in the targeting accuracy analysis.

Participants threw a Velcro-covered ball that was 1.2 cm in diameter at a carpet covered target that was their own arms' length from where they stood. Participants were instructed to reach out and touch the target with their hands in order to determine how far they needed to stand from the target. Participants were visually monitored by the experimenter to ensure that they maintained a constant distance from the target while performing the task. The target was a 1.8 cm x 1.8 cm square, centred in the middle of a 145 cm x 145 cm carpet backdrop. The carpet backdrop had a 10 cm x 10 cm grid marked on it to allow for ease of scoring. The target was 147 cm above the floor.

Participants were required to complete two separate sets of trials in which they threw the ball at the target: one involving an overhand throw, and one involving an underhand throw. Due to the closeness of the target, the movement required to project the ball to the target was necessarily more restricted during targeting performance in intrapersonal space compared to performance in extrapersonal space. Participants were given three practice trials followed by ten test trials, for each hand and type of throw (i.e., overhand or underhand). The position where the ball landed on each test trial was recorded. Scoring was completed by measuring the distance between the location where the ball hit and the closest edge of the target. The average of these distances was the participants' score for each hand and each type of throw.

Extrapersonal laser targeting. Participants performed an extrapersonal laser targeting task as described in Sykes Tottenham et al. (2005). Participants aimed a laser pointer at a target that was 230 cm from where they stood. The target board was a 56 cm x 71 cm piece of cardboard with ten separate, randomly placed targets drawn on it. The targets were numbered circles that were 4.2 cm in

diameter. The centre of the target board was 158.5 cm above the floor. The design of the laser targeting tasks necessarily differed from the design of the projectile and rolling targeting tasks in two ways: 1) multiple targets were needed so that the participants would not simply hold the laser in a stationary position between trials; and 2) the distance between the participant and the target was shorter, owing to the smaller size of the laser point compared to the ball.

Participants were required to aim the laser at the specified numbered target (as indicated by the researcher). Participants were instructed to 'aim, click, and release the button' on the laser pointer so as to keep each trial separate, instead of one continuous laser path. The laser point was only visible during the 'clicking of the button,' thus not allowing for any online or offline correction during the trial. Participants were given ten practice trials, followed by ten test trials for each hand. Results were recorded using a video camera, and scoring was performed frame by frame using a video cassette recorder and a television, in order to determine where the laser first hit the target board for each trial. Each test trial was scored by measuring the distance between the place where the laser first appeared and the closest edge of the target. The average of these distances was the participants' score for each hand.

Intrapersonal laser targeting. Participants were required to stand at arms' length from the target board, and aim a laser pointer at a specified target. Participants were visually monitored by the experimenter to ensure that they maintained a constant distance from the target while performing the task. The centre of the target board was 138 cm above the floor. The target board was a 21.5 cm x 28 cm piece of cardboard with ten separate, randomly placed targets drawn on it. The targets were lettered circles that were 1.6 cm in diameter. The procedure and scoring for the intrapersonal laser targeting task is the same as the above described procedure and scoring for the extrapersonal laser targeting task.

Extrapersonal rolling targeting. Participants rolled a ball that was 4.2 cm in diameter along the floor at a target that was 285 cm from where they were kneeling on the floor. The target was a 6.5 cm x 6.5 cm square that was centred at the bottom of a 30 cm (height) x 200 cm (width) paper backdrop. The paper

backdrop had a 10cm x 10cm grid marked on it to allow for ease of scoring. The bottom of the paper backdrop and the bottom of the target were resting on the floor.

Participants were required to roll the ball toward the target using an underhanded arm movement. Participants were given three practice trials followed by ten test trials, for each hand. The position where the ball hit the target was recorded. Scoring was completed by measuring the distance between the place where the ball initially hit the backdrop and the closest edge of the target. The average of these distances was the participants' score for each hand. Performance on this task was videotaped to ensure accuracy of scoring.

Intrapersonal rolling targeting. As described above, for the intrapersonal rolling targeting task, we proportionately scaled down the size of the ball and target. Again, this was done so as to ensure that the difficulty of the intrapersonal and extrapersonal rolling tasks were comparable.

Participants rolled a ball that was 1.2 cm in diameter along the floor at a target that was their own arms' length from where they were kneeling on the floor. Participants were instructed to reach out and touch the target with their hands in order to determine how far back from the target they should kneel. The distance between the participant and the target was recorded. Participants were visually monitored by the experimenter to ensure that they maintained a constant distance from the target while performing the task. Again, due to the proximity of the target, the movement required to project the ball to the target was necessarily more restricted during targeting performance in intrapersonal space compared to performance in extrapersonal space. The target was a 1.8 cm x 1.8 cm square, centred along the bottom of a 30 cm (height) x 200 cm (width) paper backdrop. The paper backdrop had a 10 cm x 10 cm grid marked on it to allow for ease of scoring. The bottom of the paper backdrop and the bottom of the target were resting on the floor.

Participants were required to roll the ball toward the target using an underhanded arm movement. Participants were given three practice trials followed by ten test trials, for each hand. The position where the ball landed on

each test trial was recorded. Scoring was completed by measuring the distance between the place where the ball initially hit the backdrop and the closest edge of the target. The average of these distances was the participants' score for each hand. Performance on this task was videotaped to ensure accuracy of scoring.

Purdue pegboard (PP). The PP was used as an intrapersonal motor task on which women typically demonstrate an advantage (Tiffin, 1968). Participants were required to pick up pegs one at a time from the cup in the board, and then place them in the holes in the board one at a time. This was done until all of the holes in the board were filled. The time to complete the task was recorded, and was used as the participants' score. The PP was completed in a standard fashion, with each participant performing three trials: one with the right hand, one with the left hand, and one with both hands at the same time.

Mental rotations test (MRT). Participants performed the MRT, described by Vandenberg and Kuse (1978). Participants were shown a depiction of a 3-dimensional object constructed of blocks, and were then required to pick two rotated objects (out of a choice of four) that were the same as the original one. Participants were given three practice trials, followed by 12 test trials. Participants had 4 minutes to complete as many of the 12 test trials as possible. Performance on the MRT was scored in accordance with the standardized scoring criteria, in which scores were corrected for guessing. The maximum score obtainable on the MRT was 24, and the minimum was zero.

Throwing and aiming experience questionnaire. Participants completed a throwing and aiming experience questionnaire. Participants were asked: 1) to indicate the number of activities that they had participated in throughout their life that involved either throwing (e.g., baseball, basketball, bowling, darts, etc.) or aiming (arcade games, using a laser pointer, shooting a gun, etc.); 2) to rate their experience level with throwing or aiming activities (self-assessment, 7 point Likert-type scale); and 3) to indicate their current involvement in throwing and aiming activities (number of times per month). Participants were told that 'throwing' activities were those that involved a component of aim as well as a physical thrust and release of an object (as such, bowling was classified as a

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throwing activity), whereas 'aiming' activities were those that involved aim, but did not require an object to be physically thrust and released.

Demographics and laterality questionnaire. Participants completed the demographics and laterality questionnaire described by Elias, Bryden, and Bulman-Fleming (1998).

Arm length measurement. Participants had their arm lengths measured in order to determine the distance that they would stand or kneel from the targets on the intrapersonal targeting tasks. Arm length was determined by having participants fully extend both of their arms, making it so that their fingertips touched a wall that was directly in front of them. They then lowered their arms, while remaining stationary. The experimenter then measured the distance between the wall and the participant's shoulder in order to determine arm length.

Procedure

All participants were tested individually by the same researcher. The testing session began with participants providing informed consent and completing the questionnaires. Following completion of the questionnaires participants had their arm length measured, and then performed the targeting tasks, the MRT, and the PP. The order of the tasks was counterbalanced among participants. Participants were required to complete the targeting tasks with both their right and left hands.

<div align="center">Results</div>

Preliminary Analysis

Before examining the effects of proximity and movement type on the measures of targeting accuracy, we wanted to ensure that our sample demonstrated the typically observed male advantage on the MRT task (Vandenberg & Kuse, 1978) and the typically observed female advantage on the PP (Tiffin, 1968).

Purdue pegboard. A repeated-measures ANOVA was performed for the PP. The participants' performance was analysed using sex (male, female) as the between subjects independent variable, and hand (right, left, both) as the within subjects independent variable. The dependent measure was the time it took to

complete the task. The reliability of the PP was determined using Cronbach's Alpha, and was found to be reliable (α=0.82).

As expected there was a significant main effect of sex, $F(1, 58)$=10.78, p=0.002, η^2=0.16, with women performing significantly faster than men (men: M= 55.70 sec., SD= 5.46; women: M= 51.31 sec., SD= 4.88). Also, there was a significant main effect of hand, $F(1, 58)$=248.04, p<0.001, η^2=0.81. Post hoc analysis indicated that the right hand was significantly faster than the left hand and both hands, and that the left hand was significantly faster than both hands (right: M= 47.82, SD= 6.06; left: M= 52.20, SD= 6.41; both hands: M= 60.50, SD= 7.00). The interaction between hand and sex was not significant.

Mental rotations test. An independent samples T-test was used to analyse performance on the MRT. Sex (male, female) was used as the independent between subjects variable and MRT score was used as the dependent variable. As expected, there was a main effect of sex favouring men, $t(58)$=4.23, p<0.001 (men: M= 13.67, SD= 5.44; women: M= 8.27, SD= 4.39).

Given that our sample demonstrated the typically observed sex differences on the MRT and PP, we felt confident that our sample was comparable to previous reports in their spatial and fine motor skills, and thus we proceeded to examine how task manipulations affected targeting accuracy.

Targeting Tasks

Separate repeated-measures ANCOVAs were performed for each hand. In each analysis the participants' targeting accuracy was analysed using sex (male, female) as the between subjects independent variable, and proximity (intrapersonal, extrapersonal) and type (underhand projectile targeting, overhand projectile targeting, laser targeting, rolling targeting) as the within subjects independent variables. The dependent variable for each analysis was a ratio error score for the targeting tasks. To control for differences in difficulty between the intrapersonal and extrapersonal targeting tasks, a ratio error score was used in lieu of the absolute error score. The ratio error score was computed by dividing the average distance between the first 'hit' point and the closest edge of the target (i.e., the absolute error score) by the distance that the participant stood from the

target. Arm length measurements (i.e., the distance the participant stood from the target) ranged between 60cm and 85cm (M=72.9cm, SD=5.57cm).

The ANCOVAs were initially performed using arm-length, the composite throwing experience score, and the composite aiming experience score as the covariates. However, because none of the covariates were significant for right handed targeting (arm length: $F(1, 54)= 0.001$, $p=0.97$, $\eta^2<0.001$; throwing experience: $F(1, 54)= 0.19$, $p=0.35$, $\eta^2=0.03$; aiming experience: $F(1, 54)= 2.64$, $p=0.11$, $\eta^2=0.05$), the results of the ANOVA are reported instead. For the left hand, only the covariate of throwing experience was significant (arm length: $F(1, 54)= 1.09$, $p=0.30$, $\eta^2=0.02$; throwing experience: $F(1, 54)= 6.23$, $p=0.02$, $\eta^2=0.10$; aiming experience: $F(1, 54)= 3.31$, $p=0.08$, $\eta^2=0.06$); thus, the ANCOVA results reported below include only the covariate of throwing experience.

All of the targeting tasks were determined to be reliable using Cronbach's Alpha (underhand projectile targeting: $\alpha=0.82$; overhand projectile targeting: $\alpha=0.83$; laser targeting: $\alpha=0.78$; rolling targeting: $\alpha=0.70$).

Right hand targeting. For the right handed targeting tasks there was a significant main effect of sex, favouring men, $F(1, 58)= 14.00$, $p<0.0001$, $\eta^2=0.19$ (Men: M=0.07, SD=0.04; Women: M=0.10, SD=0.04). There was also a significant main effect of type, $F(3, 174)= 169.84$, $p<0.0001$, $\eta^2=0.75$ (underhand projectile: M=0.05, SD=0.02; overhand projectile: M=0.02, SD=0.02; laser: M=0.24, SD=0.12; rolling: M=0.03, SD=0.02). The main effect of proximity was not significant, $F(1, 58)= 2.31$, $p=0.13$, $\eta^2=0.04$. Contrary to our expectations, the proximity by sex interaction and the type by sex interaction were not significant, $F(1, 58)= 0.05$, $p=0.83$, $\eta^2=0.001$, and $F(3, 174)= 2.28$, $p=0.08$, $\eta^2=0.04$, respectively. The proximity by type interaction was significant, $F(3, 174)= 8.79$, $p<0.0001$, $\eta^2=0.13$.

An examination of the simple main effects of proximity on each type of targeting shows that underhand projectile targeting was significantly more accurate in extrapersonal space than intrapersonal space, $t(59)= 3.64$, $p=0.001$

(extrapersonal: M=0.04, SD=0.02; intrapersonal: M=0.06, SD=0.04), and laser targeting was significantly more accurate in intrapersonal space than extrapersonal space, $t(59)= -2.66$, $p=0.01$ (extrapersonal: M=0.27, SD=0.15; intrapersonal: M=0.22, SD=0.14). However, no significant differences were found between extrapersonal and intrapersonal targeting accuracy on the overhand projectile and the rolling targeting tasks, $t(59)= -0.43$, $p=0.67$, and $t(59)= -0.41$, $p=0.69$, respectively. Finally, the three-way interaction (proximity by type by sex) was not significant, $F(3, 174)= 0.22$, $p=0.88$, $\eta^2=0.004$.

 Left hand targeting. Results showed that there was a significant main effect of sex, favouring men, $F(1, 57)= 28.02$, $p<0.0001$, $\eta^2=0.33$ (Men: M=0.09, SD=0.04; Women: M=0.13, SD=0.04). There was also a significant main effect of proximity, $F(1, 57)= 21.83$, $p<0.0001$, $\eta^2=0.28$, indicating that performance in intrapersonal space was significantly more accurate than performance in extrapersonal space (intrapersonal: M=0.09, SD=0.03; extrapersonal: M=0.12, SD=0.05). Further there was a significant main effect of type, $F(3, 171)= 281.71$, $p<0.0001$, $\eta^2=0.83$ (underhand projectile: M=0.05, SD=0.02; overhand projectile: M=0.04, SD=0.02; laser: M=0.30, SD=0.12; rolling: M=0.03, SD=0.02). The proximity by sex, type by sex, and proximity by type interactions were all significant, $F(1, 57)= 6.45$, $p=0.01$, $\eta^2=0.10$, $F(3, 171)= 5.98$, $p=0.001$, $\eta^2=0.10$, and $F(3, 171)= 25.47$, $p<0.0001$, $\eta^2=0.31$, respectively. However, these significant main effects and interactions were superseded by a significant three-way interaction (proximity by type by sex), $F(3, 171)= 7.29$, $p<0.0001$ $\eta^2=0.11$, which indicates that both proximity and task type affect the sex difference observed on left handed targeting tasks.

 In order to interpret the three-way interaction, we examined the simple main effects of sex and proximity within each type of targeting. Separate repeated measures ANOVAs were performed for each type of targeting performed with the left hand. Sex (male, female) was used as the between subjects independent variable, proximity (intrapersonal, extrapersonal) was the within subjects independent variable, and the ratio error score was the dependent variable in each analysis. There was a significant simple main effect of sex (favouring males) for

each of the left-handed targeting tasks (underhand projectile: $F(1, 58)= 16.14$, $p<0.0001$, $\eta^2=0.22$; overhand projectile: $F(1, 58)= 34.17$, $p<0.0001$, $\eta^2=0.37$; laser: $F(1, 58)= 10.50$, $p=0.002$, $\eta^2=0.15$; rolling: $F(1, 58)= 14.88$, $p<0.0001$, $\eta^2=0.20$ (see table 1). There was a significant simple main effect of proximity (favouring intrapersonal space) for the overhand projectile and laser targeting tasks, $F(1, 58)= 9.99$, $p=0.003$, $\eta^2=0.15$, and $F(1, 58)= 27.28$, $p<0.0001$, $\eta^2=0.32$, respectively (see table 2). There was also a significant simple main effect of proximity (favouring extrapersonal space) for the underhand projectile targeting task, $F(1, 58)= 4.65$, $p=0.04$, $\eta^2=0.07$ (see table 2). There was no significant simple main effect of proximity for the rolling targeting task, $F(1, 58)= 0.009$, $p=0.93$, $\eta^2<0.001$ (see table 2). Finally, upon examining the simple interaction effects, we found a significant sex by proximity interaction for the laser targeting task, $F(1, 58)= 7.88$, $p=0.007$, $\eta^2=0.12$ (see Figure 1). Post hoc analysis of this interaction indicated that men target significantly more accurately with their left hand in extrapersonal space, but this sex difference was no longer significant in intrapersonal space, $t(58)=-3.74$, $p<0.001$, and $t(58)=-1.07$, $p=0.29$, respectively. The interaction between sex and proximity failed to be significant for the underhand projectile and rolling targeting tasks, $F(1, 58)= 0.04$, $p=0.85$, $\eta^2=0.001$, and $F(1, 58)= 0.36$, $p=0.55$, $\eta^2=0.006$, respectively, and marginally failed to reach significance for the overhand projectile targeting task, $F(1, 58)= 3.54$, $p=0.07$, $\eta^2=0.06$.

Correlations among the Motor Tasks

Pearson Correlations were used in order to determine the degree of relatedness among the targeting tasks, the MRT, and the PP. The MRT scores were multiplied by -1 so that the directional value of the scores were comparable to the targeting and PP scores (i.e., a lower score indicates better performance). In order to reduce the number of comparisons made, the results of the right and left hand were averaged for the targeting tasks and the PP. However, in order to avoid inflating correlations owing to sex differences on the tasks, the correlations among tasks were analysed separately for the male and female samples (table 3).

Discussion

A significant sex by task by proximity interaction was observed for left handed targeting only. Further examination of the simple main effects of this interaction showed that the sex by proximity interaction was only significant for the laser targeting task. This significant interaction indicated that a male advantage was present on the extrapersonal laser targeting task, but that there was no significant sex difference on the intrapersonal laser targeting task. As such, it appears that proximity significantly mediated the sex difference observed in targeting when the task involved fine motor movements, but not when the tasks involved predominantly gross motor movements. These results largely support our current hypothesis; however, we had also expected to observe significant proximity by sex interactions, with women's targeting accuracy improving in intrapersonal space for the predominantly gross motor targeting tasks as well, albeit to a lesser extent than the fine motor task. It may be of interest to note that although the movements required for the intrapersonal and extrapersonal fine motor targeting tasks were nearly identical, the movements required for the intrapersonal gross motor targeting tasks were necessarily more restricted than the extrapersonal gross motor targeting tasks. In light of this, the significant proximity by sex interaction on the fine motor targeting tasks is more striking, considering that they entailed nearly identical motor movement. Had the interaction been significant for the gross motor targeting tasks that utilized more variable movements, the results may have been attributable to the greater restriction placed on the gross motor movements in intrapersonal space.

These results are congruent with the results of our previous study; there was a significant sex by proximity interaction on a laser aiming task in both studies, however, in the previous study the male advantage on the laser targeting task was significant in both near (88cm) and extrapersonal (230) space, with the effect being greater in extrapersonal space (Sykes Tottenham et al., 2005). In the current study, the sex difference on the laser targeting task went away when it was performed in intrapersonal space (within arms reach- mean arm length was 72.9cm). This suggests that the spatial, motor and/or visual systems that underlie

this task are very sensitive to the proxemic domain in which the task is performed, as even a very small difference in distance from the target (i.e., approximately 15cm) may be enough to negate a sex difference on motor tasks. Note, however, that the sex difference was not negated in intrapersonal space as a result of women being closer to the target as arm-length was not a significant covariate. Thus, it appears that the task must be performed within each participant's subjectively defined near proximal domain (i.e., intrapersonal space) in order for the sex difference to be negated.

We had predicted that the targeting tasks would be correlated with one another, given the underlying attribute of accurate aim. Although we did find some significant positive correlations for the targeting tasks (men: 4; women: 7), caution must be taken in interpreting these results, given the high number of correlational analyses that were performed (28 for each sex). As well, there were some unexpected results. For instance, although the fine motor tasks (PP and both laser targeting tasks) were positively correlated for the female sample, they were not significantly correlated in the male sample. Although our data do not allow us to interpret with any certainty why there is a sex difference in the degree of correlation that is found between the fine motor targeting tasks and the PP, one can speculate. The significant correlation in the female sample may be reflective of similar underlying neural mechanisms being recruited, as the tasks shared proxemic and motoric qualities. The lack of a correlation in the male sample may demonstrate that other differences in the tasks may be related to performance, for instance the PP required both fast and accurate aiming movements, whereas the laser aiming tasks did not have the requirement of speed. As such, these results may indicate that men and women utilize different spatial-motor strategies when performing motor tasks. For the most part, the MRT was not correlated with targeting accuracy in either sex (surprisingly, one significant *negative* correlation was found between MRT and extrapersonal laser targeting in the male sample, and between MRT and intrapersonal overhand projectile targeting in the female sample).

Although we did not measure brain activation during the targeting tasks, the finding that a combination of both fine motor skill and intrapersonal space were required to alleviate the male advantage on targeting supports Kimura and colleague's theory (Chipman et al., 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991). However, considering the number of correlational analyses that were performed, there were very few significant correlations among the targeting tasks. Thus targeting may not be a unitary skill that ubiquitously demonstrates a male advantage, rather it is a skill that shows a male advantage due to a combination of proxemic and motoric task characteristics (i.e., as it is typically performed, it involves predominantly gross motor skill that is directed at extrapersonal space).

Although we identified two task characteristics that play a role in the sex difference observed on targeting tasks, there may be other characteristics typical of targeting tasks that also contribute to the male advantage. Because targeting is a ballistic task (i.e., once the projecting movement is initiated, there is no chance for on-line correction) precise timing of the ball release (or the button push in the case of laser targeting) is extremely important. This precise timing component may be another feature of targeting tasks at which men excel. Consistent with this hypothesis, in a sample of male recreational athletes, overhand extrapersonal projectile targeting has been found to have on average a 9.6 msec window for timing of ball release (n.b., women were not tested) (Hore, Watts, Martin, & Miller, 1995). However, the PP does not have such precise timing requirements (the peg is released once it has already contacted the target) and typically exhibits a female advantage. Similarly, Barral and Debu (2004) observed a female advantage on a targeting task in which participants touched targets with their finger, which did not require precise timing of a release of a projectile. Thus, the requirement of precise timing for the ball release (or the button push) may be another aspect of targeting that allows for the male advantage.

Another difference between the requirements of our measures and those of Barral and Debu (2004) was that our targeting tasks only required accurate aiming movements, whereas the others required participants to make fast and accurate

aiming movements. Thus, it may be that the speeded nature of these tasks accounts for the female advantage on the PP, the GP, and the Barral and Debu task. Support for this hypothesis comes from Nicholson and Kimura (1996) who demonstrated that women outperform men on the repetition of a sequence of manual movements when baseline motor speed is accounted for.

In conclusion, the results of our study suggest that the sex difference observed on targeting tasks may be due in part to the task's typical motor and proxemic characteristics (i.e., predominantly gross motor movements directed at extrapersonal space), as the male advantage was non-significant for the intrapersonal fine motor targeting task. Other factors, such as the timing of ball release or button push, may also help to account for the observed sex difference on targeting tasks. By further understanding the mechanisms of targeting that are responsible for the sex difference (e.g., proximity, possibly timing of ball release, etc.), we may be able to work towards levelling the playing field by training women and girls to focus on the factors that may allow them to excel at targeting tasks.

Acknowledgments

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Table 1

Left-handed Targeting Tasks by Sex: Mean Ratio Error Score (SD)

Task	Men	Women
Underhand Projectile*	0.044 (0.019)	0.063 (0.029)
Overhand Projectile	0.028 (0.015)	0.049 (0.022)
Laser	0.253 (0.112)	0.348 (0.163)
Rolling	0.023 (0.016)	0.043 (0.037)

*on all tasks a high score indicates poorer performance than a low score

Table 2

Left-handed Targeting Tasks by Proximity: Mean Ratio Error Score (SD)

Task	Intrapersonal	Extrapersonal
Underhand Projectile*	0.058 (0.028)	0.048 (0.024)
Overhand Projectile	0.033 (0.019)	0.044 (0.024)
Laser	0.226 (0.117)	0.359 (0.181)
Rolling	0.033 (0.040)	0.033 (0.021)

*on all tasks a high score indicates poorer performance than a low score

Table 3

*Intercorrelations among the Targeting Tasks, MRT, and the PP* (n=60)

Tasks	1	2	3	4	5	6	7	8	9	10
1-Extrapersonal Underhand										
men	-	.15	.26	-.05	-.16	.26	.39*	.45**	-.13	.14
women	-	-.12	.60**	.18	-.02	-.17	.62**	.08	-.04	-.08
2-Intrapersonal Underhand										
men		-	-.16	.11	-.27	.04	.04	.16	-.07	.02
women		-	-.02	.39*	-.13	-.07	-.22	.29	.15	.11
3-Extrapersonal Overhand										
men			-	-.04	.17	.20	.14	.32*	.19	.20
women			-	.35*	.27	-.01	.29	.31*	.003	-.13
4-Intrapersonal Overhand										
men				-	-.24	-.26	-.01	.27	-.22	-.06
women				-	-.33*	-.35*	-.21	.78**	-.24	-.43*
5-Extrapersonal Laser										
men					-	.33*	.22	.37*	-.12	-.39*
women					-	.59**	.16	-.20	.41*	.30
6-Intrapersonal Laser										
men						-	.04	-.002	.01	-.29
women						-	.03	-.21	.38*	.30
7-Extrapersonal Rolling										
men							-	.26	-.32*	-.03
women							-	-.36*	.11	-.12
8- Intrapersonal Rolling										
men								-	.34*	.19
women								-	-.17	-.19
9- Purdue Pegboard										
men									-	.23
women									-	.07
10- MRT										
men										-
women										-

* significant at *p*<0.05 (1-tailed)
** significant at *p*<0.01 (1-tailed)

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Figure Caption

Figure 1.   The significant interaction between sex and proximity for the left hand laser targeting task. Values are mean ratio error scores +/- SEM.
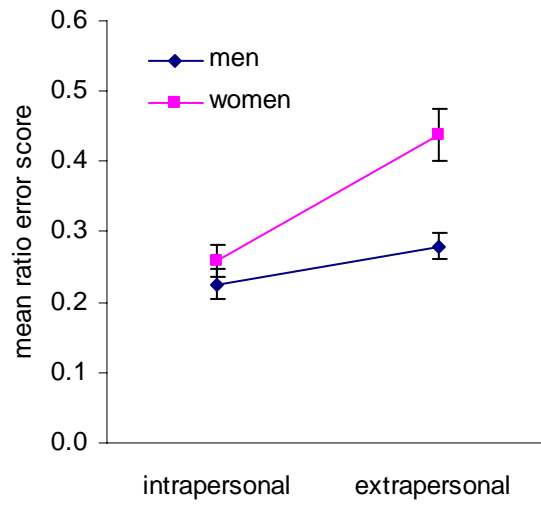
Rationale for Study 3

The purpose of the third study was to examine the relations among circulating concentrations of sex hormones, an estimator of prenatal exposure to sex hormones and targeting accuracy within samples of men and women. Research is scarce pertaining to the role that either prenatal or circulating sex hormones have on targeting accuracy. The few studies that have been performed have shown that both prenatal and circulating androgenic and estrogenic hormones are related to targeting accuracy (Hines et al, 2003; Janowsky et al., 1998; Sanders & Kadam, 2001; Saucier & Kimura, 1998). However, the results are not consistent among studies, and in one case the results are not even consistent between sessions within the same study (i.e., Janowsky et al.).

Two studies have been conducted that evaluated the relation between prenatal exposure to androgens and subsequent targeting accuracy. Hines and colleagues (2003) investigated the relation between prenatal exposure to atypically high concentrations of T and targeting accuracy by comparing a sample of male and female individuals with CAH to a sample of hormonally normal individuals. They found that prenatal exposure to atypically high concentrations of T was associated with enhanced targeting accuracy in adolescent/adult women; a relation was not observed in their sample of adolescent/adult men. Sanders and Kadam (2001) examined the relation between relative prenatal T concentrations and targeting accuracy in children by using an estimator of relative prenatal T concentrations (i.e., FRC asymmetry). They found that boys and girls with a rightward FRC asymmetry significantly outperformed their same sex counterparts who had leftward FRC asymmetries on a targeting task. Their findings suggest that prenatal exposure to relatively high concentrations of T is associated with enhanced targeting accuracy in prepubescent girls (as was also found by Hines and colleagues) and boys (which was not found by Hines and colleagues).

Similar to FRC, the ratio between the length of the index finger (2D) and the length of the ring finger (4D), hereafter referred to as the 2D:4D ratio, is an indirect means of estimating relative prenatal exposure to sex hormones. This ratio is present by the 14th week of pregnancy and is stable throughout life (Garn,

Burdi, & Babler, 1975). A low 2D:4D ratio is associated with exposure to relatively high concentrations of T relative to E prenatally (hereafter referred to as T/E), whereas a high 2D:4D ratio is associated with exposure to relatively low T/E concentrations prenatally (Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer, & Manning, 2004). Although previous research has suggested a relation between prenatal sex hormone concentrations and both the 2D:4D ratio and FRC asymmetry, direct evidence for this relation has been found only for the 2D:4D ratio (i.e., Lutchmaya et al.). As such, in Study 3, I chose to utilize the 2D:4D ratio as an estimator of prenatal exposure to sex hormones instead of FRC asymmetries.

In adults, two studies have examined the relation between circulating levels of T and targeting accuracy. Janowsky and colleagues (1998) found that relatively low circulating T concentrations were associated with enhanced targeting accuracy in men and that relatively low circulating T and E concentrations were associated with enhanced non-dominant hand and impaired dominant hand targeting accuracy in women. However, Janowsky and colleagues only found significant correlations in their second of two sessions. Saucier and Kimura (1998) reported results for their sample of women that were similar to Janowsky and colleagues' results. They found that relatively low circulating E and P concentrations were associated with enhanced targeting accuracy of the non-dominant hand, whereas relatively high circulating E and P concentrations were associated with enhanced targeting accuracy of the dominant hand.

Thus, previous studies have only examined the relation between targeting accuracy and either prenatal or circulating sex hormones. Study 3 used a combination of methods (direct and indirect) to examine the effects that both prenatal and circulating sex hormones have on targeting accuracy within samples of men and women, As such, Study 3 allowed for the examination of a potentially interactive effect of activational and organization hormones on targeting accuracy; an effect that may account for the inconsistencies noted in the previously conducted studies.

Study 3

Cover Page

Title: Organizational and Activational Effects of Sex Hormones on Targeting Accuracy in Men and Women

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Organizational and Activational Effects of Sex Hormones on

Targeting Accuracy in Men and Women

Abstract

Targeting is a spatial motor task that shows a consistent sex difference favouring men. Independent studies have suggested that either prenatal exposure to sex hormones or circulating sex hormone concentrations relate to sex differences in targeting accuracy. However, within the same sample, the potentially interactive effect of prenatal exposure to sex hormones and circulating sex hormone concentrations on targeting accuracy has not been investigated yet. We investigated the relations among targeting accuracy and: an estimate of prenatal exposure to sex hormones (the 2D:4D ratio), current circulating concentrations of testosterone (T) (determined by salivary assays- men only), and menstrual phase and oral contraceptive use (women only). Results for the men demonstrated a significant interaction between prenatal exposure to sex hormones and circulating T concentrations, indicating that men who were prenatally exposed to high T relative to estradiol (E) concentrations (i.e., those who showed a low 2D:4D ratio) and who had relatively high circulating T concentrations were significantly less accurate at hitting the target than all other groups of men. Results for the women demonstrated that women prenatally exposed to relatively high T relative to E concentrations targeted significantly more accurately than women exposed to relatively low T relative to E concentrations prenatally. Further, a significant menstrual phase by oral contraceptive use interaction for targeting accuracy was found, which indicated that women using oral contraceptives were significantly more accurate at hitting the target at the menstrual phase (no pill phase) as compared to the midluteal phase (while taking pills); no significant phase differences were observed in naturally cycling women. Results are discussed with respect to the differing organizational and activational effects of sex hormones on targeting accuracy in men and women.

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Organizational and Activational Effects of Sex Hormones on

Targeting Accuracy in Men and Women

Targeting is a spatial motor task that requires participants to accurately project an object to a target. Previous studies have demonstrated that men consistently throw projectiles at targets significantly more accurately than women (e.g., Hall & Kimura, 1995; Sykes Tottenham & Saucier, 2004; Watson & Kimura, 1989; Watson & Kimura, 1991). Numerous researchers have found that the sex difference in targeting accuracy is not explained by sex differences in: previous sports and throwing experience (Hall & Kimura; Sykes Tottenham & Saucier, 2004; Watson & Kimura, 1989; Watson & Kimura, 1991); size and muscularity (Hall & Kimura; Lunn & Kimura, 1989); or the ability to calibrate subsequent throws (Sykes Tottenham & Saucier, 2004). Further, this sex difference in targeting accuracy does not appear to be dependent upon: the orientation of the target (i.e., horizontal or vertical) (Jardine & Martin, 1983); or the type of throw or projectile employed (i.e., under- or over-hand throws, using a ball or dart) (e.g., Hall & Kimura; Hines et al., 2003; Janowsky, Chavez, Zamboni, & Orwoll; 1998). Some researchers have, however, found a relation between prenatal exposure to sex hormones and targeting accuracy (Hines et al.; Sanders & Kadam, 2001), while others have found a relation between circulating sex hormone concentrations and targeting accuracy (Janowsky et al.; Saucier & Kimura, 1998).

However, to date no one has examined the influences of both prenatal and circulating sex hormones within the same individual when examining targeting accuracy in adulthood. As such, the purpose of the current study is to extend the findings of the aforementioned studies by investigating the relations among targeting accuracy and both prenatal and circulating sex hormone concentrations within the same sample.

Sex Hormones and Targeting Accuracy

Prenatal exposure to sex hormones. Prenatal exposure to sex hormones has permanent organizational effects on the brain and behaviour of humans and rodents (e.g., Arnold & Gorski, 1984; Collaer & Hines, 1995; Williams & Meck,

1991). It appears that exposure to prenatal testosterone (T) masculinizes the brain, however, it does so by being aromatized to estradiol (E); maternal estrogens do not masculinize the fetal brain because they are bound by alpha-feto-protein (AFP) (for review see Breedlove & Hampson, 2002).

A relation between targeting accuracy and prenatal sex hormone concentrations has been reported (Hines et al., 2003; Sanders & Kadam, 2001). Prenatal exposure to abnormally high levels of androgens as a result of congenital adrenal hyperplasia (CAH) resulted in enhanced targeting accuracy in women with CAH compared to women in the control group (Hines et al.). However, no significant differences were found when comparing men with CAH to controls (Hines et al.), which is consistent with other papers that have failed to observe significant differences between men with CAH and unaffected controls for other activities (e.g., Berenbaum & Hines, 1992; Perlman, 1973; Resnick, Berenbaum, Gottesman, & Bouchard, 1986).

Sanders and Kadam (2001) examined the relation between targeting accuracy and finger ridge count (FRC) asymmetry in prepubescent boys and girls. Exposure to relatively high concentrations of T prior to the 16th week of fetal development is related to a FRC asymmetry that is greater on the right hand than the left hand (Jamison, 1990; Kimura & Carson, 1995). Boys and girls with a rightward FRC asymmetry significantly outperformed boys and girls with a leftward FRC asymmetry on a targeting task (Sanders & Kadam). Sanders and Kadam conclude that prenatal exposure to relatively high concentrations of T was associated with enhanced targeting accuracy in boys and girls. Further, as their sample had not undergone puberty, it is unlikely that circulating levels of sex hormones were responsible for the observed sex difference.

In the current investigation we indirectly examined prenatal hormone concentrations by using the ratio of the length of the index finger (2D) to the ring finger (4D). This sexually dimorphic ratio (2D:4D ratio) reflects the relative prenatal exposure to sex hormones (Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer, & Manning, 2004). In women, the 2D is typically of equal length or longer than the 4D, whereas men typically have a longer 4D than 2D (for review

see Manning, 2002). Amniocentesis has confirmed that high, but normal, ratios of prenatal concentrations of T relative to prenatal concentrations of E (hereafter referred to as prenatal T/E ratio) are associated with a low 2D:4D ratio (Lutchmaya et al., 2004). Conversely, a high 2D:4D ratio is associated with a relatively low prenatal T/E ratio. This asymmetry is also observed in individuals with CAH, who have a lower 2D:4D ratio than non-affected controls (Brown, Hines, Fane, & Breedlove, 2002; Ökten, Kalyoncu, & Yaris, 2002).

Circulating sex hormone concentrations. Although the organizational effects of differential exposure to sex hormones result in differences in brain structures and functions, concentrations of circulating sex hormones also influence behaviour (for review see Kimura & Hampson, 1994). For instance, women with relatively high levels of circulating T consistently outperform women with relatively low levels of circulating T on tasks of spatial ability, whereas men with relatively low levels of circulating T outperform men with relatively high levels of circulating T on tasks of spatial ability (Gouchie & Kimura, 1991).

In women, the activational effects of E can be observed across the menstrual cycle and by comparing those who take exogenous estrogens (i.e., oral contraceptives, OCs) with those who do not. OCs artificially sustain E and P concentrations at an elevated level across the menstrual cycle and they raise sex-hormone binding globulin (SHBG), which decreases levels of unbound T (van der Vange, Blankenstein, Kloosterboer, Haspels, & Thijssen, 1990). Activational effects of circulating T concentrations can also be directly studied by sampling and assaying circulating T concentrations in saliva or blood. However, previous research has shown that, in women, salivary assays of unbound circulating T concentrations (i.e., bioactive T) are not correlated with serum blood assays of unbound T concentrations (Shirtcliff, Granger, & Likos, 2002). As such, salivary assays of circulating T concentrations should not be used to examine the activational effects of T on women's performance.

Very little research has examined the activational effects that either circulating T or E concentrations have on targeting accuracy. Saucier and Kimura

(1998) examined this relation in naturally cycling women (NoOC women) across the menstrual cycle (confirmed through salivary assays) and found that the non-dominant hand was more accurate during the menstrual phase (low-E) than during the midluteal phase (high E). Conversely, the dominant hand was more accurate during the menstrual phase than the midluteal phase.

Janowsky et al. (1998) examined whether circulating concentrations of T and E concentrations relate to targeting accuracy using serum blood assays. Circulating concentrations of E were only significantly negatively correlated with targeting accuracy in a very restricted subset of their sample: only in women during the second session of testing when they were targeting with their non-dominant hand. For the relation between circulating concentrations of T and targeting accuracy, significant and negative correlations were observed during the second session of testing for men (both hands) and for women targeting with their non-dominant hand. However, when targeting with their dominant hand, women actually showed a positive correlation between targeting accuracy and circulating T concentrations. Generally speaking it appears that relatively high circulating concentrations of T are associated with poorer targeting accuracy in men, but for women this relation is variable and may depend upon the hand used to perform the task. Given the lack of significant results for the first session of testing, it is difficult to interpret the results of Janowsky and colleagues with any certainty.

Although Sanders and Kadam (2001) propose that the sex difference observed in targeting accuracy is due to the organizational effects of sex hormones, the above noted studies suggest that targeting is also affected by the activational effects of sex hormones. Our study investigated the activational effects of circulating T concentrations (as determined by salivary T enzyme linked immunosorbent assay, ELISA) on targeting accuracy in men, and the relations among targeting accuracy, menstrual phase, and oral contraceptive use in women, while also accounting for prenatal exposure to sex hormones (as indicated by the 2D:4D ratio).

Current Aims and Hypotheses

Because one major difference between the sexes is the extent to which they are exposed to androgenic or estrogenic sex hormones both before birth and in adult life, it is important to account for both the activational and organizational influences of sex hormones when examining any behavioural or structural sex difference observed in adulthood.

In this study we examined the effects of exposure to sex hormones at both organizational and activational periods on targeting accuracy in men and women. Based on the studies reviewed above, we made the following predictions:

1. men would target significantly more accurately than women

2. men and women exposed to a relatively high prenatal T/E ratio (as indicated by the 2D:4D ratio) would target significantly more accurately than their same-sex counterparts exposed to a relatively low prenatal T/E ratio;

3. women at the high E phase of their menstrual cycle would target significantly more accurately with their dominant hand and less accurately with their non-dominant hand than women at the low E phase of their menstrual cycle;

4. OC women would target significantly less accurately with their dominant hand, and more accurately with their non-dominant hand than NoOC women (due to suppressed circulating unbound T concentrations in OC women);

5. men with relatively high circulating T concentrations (as determined by salivary T enzyme linked immunosorbent assay, ELISA) would target significantly less accurately than men with relatively low circulating T concentrations.

However, the primary purpose of this study was to extend the current research findings related to sex hormones and targeting accuracy by examining the potentially interactive effects of both organizational and activational sex hormones on targeting accuracy within the same sample. Until now the relations among prenatal exposure to sex hormones, circulating sex hormone

concentrations, and targeting accuracy have been unclear, in part because the aforementioned studies have focused on investigating either the relation between targeting accuracy and circulating sex hormone concentrations (Janowsky et al., 1998; Saucier & Kimura, 1998), or between targeting accuracy and prenatal sex hormone concentrations (Hines et al., 2003; Sanders & Kadam, 2001). To our knowledge, no study has investigated the potentially interactive relation of exposure to sex hormones at both the organizational and activational periods on targeting accuracy. Owing to the exploratory nature of this aspect of the study, no hypotheses are being made concerning these potential interactions in our samples of men (2D:4D ratio and salivary T) and women (2D:4D ratio, menstrual phase, and oral contraceptive use). However, as noted above, we do expect to observe the typical sex difference (favouring men) on the targeting task.

<div align="center">Method</div>

Participants

Thirty-two men, 31 NoOC women, and 33 OC women participated in this study. All participants were Caucasian between the ages of 17 and 29 years (Men: M=21.34 years, SD=3.45 years; NoOC women: M=19.9 years, SD=2.7 years; OC women: M=19.6 years, SD=1.8 years), and were right handed as assessed by questionnaire (Elias, Bryden, & Bulman-Fleming, 1998). Participants were recruited through either an Introductory Psychology class (in exchange for course credit) or through posters advertising the study around campus (in exchange for a small monetary reward).

Measures

2D:4D ratio. The length of the index (2D) and ring (4D) finger was measured on the palmar surface using an Electronic Digital Calliper (Control Company, model number: 62379-531), measuring from the basal crease to the tip of each finger (Manning, 2002). All measurements were taken twice and were found to be reliable (Cronbach's alpha): left index 0.994, left ring 0.996, right index 0.995, and right ring 0.994. As such, the average value of the two measurements was used for each finger. The 2D:4D ratio was then determined by dividing the average length of 2D by the average length of 4D. This was done for

the right and left hands separately. However, as previous studies have reported greater effects when using the 2D:4D ratio from the right hand than from the left hand (Brown, Finn, Cooke, & Breedlove, 2002; Brown, Hines, Fane, & Breedlove, 2002; Lutchmaya et al., 2004; Ökten et al., 2002; Williams et al., 2000), only the right hand 2D:4D ratio was used in subsequent analyses. None of the participants included in the 2D:4D analyses had previously broken or severely injured their index or ring fingers on either hand (resulting in the exclusion of one man, two OC women, and four NoOC women from the 2D:4D analyses).

Saliva sample. Two saliva samples were collected from each participant, including the NoOC and OC women. All participants provided saliva samples so as to keep the procedure for all participants as similar as possible. However the saliva samples provided by the women were disposed of because salivary assays of unbound circulating T concentrations (i.e., bioactive T) are not correlated with serum blood assays of unbound T concentrations in women (Shirtcliff et al., 2002). Participants refrained from eating, smoking, brushing their teeth, chewing gum, and drinking (anything other than water) for at least one hour before the testing session commenced. Participants rinsed their mouths with water before providing each of the two saliva samples. To provide the samples, participants passively salivated and deposited their saliva into a collection vial that they held close to (but not in direct contact with) their lips. Participants provided approximately 2 ml of saliva for each of the samples. Immediately following collection, the samples were frozen. The samples remained frozen until all samples were collected; then the ELISAs were performed.

The saliva samples were assayed for T using a Salimetrics ELISA kit, which has a sensitivity range of 1.5-360 pg/ml (Salimetrics, State College, PA). All samples were assayed in triplicate, with the average of the triplicate values used in subsequent analyses (the average intra-assay CV was 3.73%). The saliva samples were also screened for blood contamination using a Salimetrics transferrin ELISA kit (Salimetrics, State College, PA), quantifying the levels of transferrin, an indicator of blood contamination in saliva. Again, the saliva samples were assayed in triplicate, with the average of the triplicate values used to

screen for blood contamination (the average intra-assay CV was 10.81%). As blood can contaminate saliva samples and alter subsequent T assays, only participants who provided at least one saliva sample that was uncontaminated by blood were included in the hormonal analyses (resulting in the exclusion of five men from the hormonal analyses). Samples containing 0.5 mg/dl of transferrin were considered contaminated by blood, and as such were excluded from the T analyses.

Menstrual cycle and oral contraceptive use questionnaire. Although we did try to keep the experimental procedure as similar as possible between our male and female participants, male participants were not required to complete the menstrual cycle and oral contraceptive use questionnaire. This questionnaire was administered to ensure that all female participants had regular menstrual cycles ranging from 25 to 35 days in length. Specifically, the female participants were asked about the regularity of their menstrual period, the dates that their last 2 menstrual periods started, and the date of their next expected menstruation. The average menstrual cycle length of the women in our sample was 28.6 days, with a standard deviation of 2.24 days. NoOC women were required to have been free of oral contraceptive use for a period of 6 months prior to their participation. Women were classified as being in their menstrual phase if they were tested between days 1 and 5 after the commencement of their menstrual period. Women were classified as being in the midluteal phase if they were tested 5-10 days prior to the onset of menstruation. Following participation in the study, all female participants confirmed (by phone call or e-mail) the start date of their menstrual period. Participants who did not meet the above criteria concerning menstrual phase and regularity were excluded from the data analysis (4 OC and 7 NoOC women were excluded).

Targeting. The targeting task used in this study was the same one that was reported in Saucier and Kimura (1998). Participants threw a Velcro-covered ball (4.2 cm in diameter) at a carpet covered target that was 285 cm from where they stood. The target was a 6.5 cm x 6.5 cm square that was in the middle of a 145 cm

x 145 cm carpet backdrop. The target was centered in the larger area and was 147 cm above the floor.

Participants were required to make an underhand throw with the ball to try and hit the central target. Participants were given three practice trials, followed by 10 test trials, for each hand (the order of which hand they started with was counterbalanced between participants). The distance between where the ball hit on the backdrop and the closest edge of the target was recorded for each trial. The average of the 10 trials was computed for each hand.

Throwing and aiming experience scale. Participants evaluated their past throwing and aiming experience using two 7-point Likert scales. A score of one indicated that the participant was 'not at all experienced' with throwing or aiming, whereas a score of seven indicated that they were 'extremely experienced' with throwing or aiming. Participants were asked to consider all types of throwing experience (e.g., darts, baseball, basketball, etc.), and all types of aiming experience (e.g., shooting a gun or arrow, using a laser pointer, etc.) when answering each of these questions. Note that although the throwing tasks described above also required aiming accuracy, the terms 'throwing' versus 'aiming' were used so as to differentiate between tasks that required strictly aiming accuracy, versus those that required both throwing and aiming accuracy. This distinction between throwing and aiming accuracy was required for a previous study that also utilized the throwing and aiming experience scale.

Procedure

All participants were tested individually by the same experimenter. The testing session began with participants providing informed consent. Following that, participants provided a passive saliva sample, and had their 2D:4D ratio measured. Participants then completed the throwing and aiming experience scales, the menstrual cycle and oral contraceptive use questionnaire (women only), and the targeting task with both the dominant and non-dominant hand (the order of which hand they started with was counterbalanced between participants). The testing session ended with participants providing a second passive saliva sample.

Results

Preliminary Analyses

Two independent samples t-tests were performed (separate analyses were performed for each hand) in order to ensure that our sample was comparable to previous reports with regards to the sex difference typically observed in targeting accuracy (favouring men). Sex (male, female) was the independent between subjects variable, and targeting accuracy was the dependent variable. As expected, men targeted significantly more accurately than women with both their dominant and non-dominant hands, $t(94)=-2.27$, $p=0.03$, $\eta^2= 0.05$ (men: M= 8.96cm, SD= 3.46cm; women M= 10.98cm, SD= 4.40cm), and $t(94)=-3.28$, $p=0.001$, $\eta^2= 0.10$ (men: M= 11.35cm, SD= 4.61cm; women M= 15.55cm, SD= 6.47cm), respectively.

Dichotomization of Hormonal Measures in Men

As the circulating T concentrations from the two sampling times were not significantly different, $t(19)=1.23$, $p=0.24$, the average of the circulating T concentrations from the two sampling times was computed and used in subsequent analyses. However, eight samples from the first collection time and eight samples from the second collection time were excluded due to blood contamination. As such, for seven participants only one uncontaminated sample was available, which was used in lieu of the mean of the two samples.

Using a median split (median=176.73 pg/ml), the circulating T concentrations were dichotomized and an independent samples t-test was performed using the groups created from the median split (high circulating T vs. low circulating T) as the between subjects independent variable, and actual circulating T concentrations as the dependent variable. A significant difference was found between the high T and low T groups in their circulating T concentrations, indicating that the dichotomization resulted in real between group differences ($t(25)= -5.96$, $p<0.001$; low T group: M= 114.44, SD= 29.01; high T group: M= 240.01, SD= 70.61). Further, it should be noted that the circulating T concentrations in our sample of men were not significantly correlated with their age ($r= -0.25$, $p= 0.22$), nor was the mean age of the high T group significantly

different than the low T group ($t(25)$= 1.30, p=0.20; low T group: M= 22.31 years, SD= 3.17; high T group: M= 20.71 years, SD= 3.17).

A median split was also used to dichotomize the right hand 2D:4D ratio (median=0.99). To ensure that the dichotic grouping of participants into high and low 2D:4D ratio reflected significant differences between the groups for the 2D:4D ratio, an independent samples t-test was performed using the groups created from the median split procedure (high 2D:4D ratio vs. low 2D:4D ratio) as the between subject independent variable, and the right hand 2D:4D ratio as the dependent variable. Significant differences were found between the high and low groups on the 2D:4D ratio, indicating that the dichotomization resulted in real between group differences ($t(29)$= -7.89, p<0.001; low 2D:4D ratio group: M= 0.95, SD= 0.02; high 2D:4D ratio group: M=1.00, SD= 0.01).

Men: Targeting Accuracy, Circulating Testosterone Concentrations and 2D:4D Ratio

Two 2x2 ANOVAs were performed (separate analyses were performed for the targeting accuracy of each hand). In each ANOVA the dichotomized 2D:4D group (high 2D:4D vs. low 2D:4D) and the dichotomized circulating T concentration group (high circulating T vs. low circulating T) were used as the independent between subjects variables, with targeting accuracy as the dependent variable. Initially ANCOVAs were run, using throwing and aiming experience as covariates, but because the covariates were not significant (right hand: throwing experience: $F(1,25)$=0.19, p=0.67 η^2=0.009, aiming experience: $F(1,25)$=0.01, p=0.918, η^2=0.001; left hand: throwing experience: $F(1,25)$=0.57, p=0.46, η^2=0.03, aiming experience: $F(1,25)$=1.70, p=0.21, η^2=0.08), only the results of the ANOVAs are reported.

ANOVA revealed significant differences for both the 2D:4D ratio groups and circulating T concentration groups for targeting accuracy with the dominant hand, $F(1,25)$=10.82, p=0.003, η^2=0.34, and $F(1,25)$=6.83, p=0.02, η^2=0.26, respectively. Men with a high 2D:4D ratio performed significantly better on the targeting task with the dominant hand than men with a low 2D:4D ratio (M=7.07cm deviation from target, SD=2.07, and M=9.41cm deviation from

target, SD=3.10, respectively). Men with low circulating T concentrations performed significantly better on the targeting task with the dominant hand than men with high circulating T concentrations (M=7.38cm deviation from target, SD=1.95, and M=9.10cm deviation from target, SD=3.38, respectively). Additionally, the interaction between 2D:4D ratio and circulating T concentrations was significant for targeting accuracy of the dominant hand, $F(1,25)=6.81$, $p=0.02$, $\eta^2=0.24$ (see Figure 1). Post hoc tests (Tukey's) revealed that men with a low 2D:4D ratio and relatively high circulating T concentrations performed significantly more poorly on the targeting task with the dominant hand than men with: a low 2D:4D ratio and relatively low circulating T concentrations; a high 2D:4D ratio and relatively high circulating T concentrations; and a high 2D:4D ratio and relatively low circulating T concentrations. The post hoc tests revealed no other significant differences among the groups.

Targeting accuracy of the non-dominant hand was not significantly different for either the 2D:4D ratio groups (high vs. low) or the circulating T concentration groups (high vs. low), $F(1,25)=1.58$, $p=0.22$, $\eta^2=0.07$, and $F(1,25)=1.07$, $p=0.31$, $\eta^2=0.05$, respectively. The interaction also failed to reach significance $F(1,25)=0.23$, $p=0.64$, $\eta^2=0.01$.

Dichotomization of the 2D:4D ratio in women

A median split was also used to dichotomize the right hand 2D:4D ratio (median=0.99). To ensure that the dichotic grouping of participants into high and low 2D:4D ratio reflected significant differences between the groups for the 2D:4D ratio, an independent sample t-test was performed using the groups created from the median split procedure (high 2D:4D ratio vs. low 2D:4D ratio) as the between subjects independent variable, and the right hand 2D:4D ratio as the dependent variable. Significant differences were found between the high and low groups on the 2D:4D ratio, indicating that the dichotomization resulted in real between group differences, $t(56)=-9.25$, $p<0.001$ (low 2D:4D group: M=0.95, SD=0.03; high 2D:4D group: M=1.01, SD=0.02).

*Women: Targeting Accuracy, 2D:4D Ratio, Menstrual Phase and Oral
Contraceptive Use*

Two 2x2x2 ANCOVAs were performed (separate analyses were
performed for targeting accuracy of the dominant and non-dominant hand). In
each ANCOVA the dichotomized 2D:4D group (high 2D:4D vs. low 2D:4D), the
menstrual phase groups (menstrual vs. midluteal), and the oral contraceptive use
groups (NoOC vs. OC) were used as the independent between subject variables,
throwing and aiming experience were used as covariates, and targeting accuracy
was the dependent variable.

The results of the ANCOVA revealed that women with a low 2D:4D ratio
performed significantly more accurately on the targeting task with their non-
dominant hand than women with a high 2D:4D ratio, $F(1, 47)=4.53$, $p=0.04$,
$\eta^2=0.11$ (M=13.54cm deviation from target, SD=5.68, and M=17.61cm deviation
from target, SD=6.09, respectively). There were no significant differences on
targeting accuracy with the non-dominant hand between the menstrual phase
groups, and the oral contraceptive use groups, $F(1, 47)=2.34$ $p=0.14$, $\eta^2=0.06$, and
$F(1, 47)=3.38$, $p=0.74$, $\eta^2=0.08$, respectively. However, the interaction between
the oral contraceptive use group and the menstrual phase group was significant,
$F(1, 47)=6.68$, $p=0.01$, $\eta^2=0.15$ (see figure 2). Further examination of this
interaction indicated that OC women performed significantly more accurately on
the targeting task during the menstrual phase of their cycle compared to their
midluteal phase, $t(27)=-2.69$, p=0.01 (menstrual: M=13.51, SD=4.78; midluteal:
M=19.75, SD=7.49), whereas no significant menstrual phase effects were found
for the NoOC women, $t(22)=-0.25$, $p=0.80$ (menstrual: M=14.97, SD=4.46;
midluteal: M=15.54, SD=6.35). There were no other significant interactions. The
covariate of throwing experience was found to be significant, $F(1, 47)=4.48$,
$p=0.04$, $\eta^2=0.11$, and the covariate of aiming experience was not found to be
significant, $F(1, 47)=0.26$, $p=0.61$, $\eta^2=0.01$.

The results of the ANCOVA revealed that there were no significant
differences on targeting accuracy with the dominant hand between the 2D:4D
groups, the menstrual phase groups, and the oral contraceptive use groups, $F(1,$

47)=0.66, *p*=0.42, η^2=0.02, *F*(1, 47)=1.58, *p*=0.22, η^2=0.04, and *F*(1, 47)=0.08, *p*=0.79, η^2=0.002, respectively. There were no significant interactions. However, it may be of interest to note that the only interaction to approach significance was the menstrual phase by oral contraceptive group interaction, *F*(1, 47)=2.27, *p*=0.14, η^2=0.06. This interaction demonstrated a similar (though non-significant) pattern as the significant interaction of these variables on targeting accuracy with the non-dominant hand, with OC women targeting more accurately during their menstrual phase than their midluteal phase (*t*(27)=-1.92, p=0.07; menstrual: M=9.84, SD=2.68; midluteal: M=12.43, SD=4.43), whereas NoOC women's accuracy remained fairly consistent over the menstrual cycle (*t*(22)=-0.05, p=0.96; menstrual: M=10.76, SD=4.26; midluteal: M=10.85, SD=4.15). The covariate of aiming experience was found to be significant, *F*(1, 47)=7.44, *p*=0.01, η^2=0.17, and the covariate of throwing experience was not found to be significant, *F*(1, 47)=3.06, *p*=0.09, η^2=0.08.

<div align="center">Discussion</div>

Our preliminary analysis indicated that the men in our sample targeted significantly more accurately than the women. This finding supports our first hypothesis, and is congruent with the results of other studies (e.g., Hall & Kimura, 1995; Sykes Tottenham & Saucier, 2004; Watson & Kimura, 1989; Watson & Kimura, 1991). Given that our sample demonstrated the typically observed sex difference on the targeting task, we felt confident in the normalcy of our sample, and thus we proceeded with examining within sex differences in targeting accuracy owing to hormonal variations.

The Effects of Circulating Testosterone Concentrations and Prenatal Hormone Exposure on Targeting Accuracy in Men

Our results for the male sample demonstrated a significant main effect of prenatal exposure to sex hormones (as indicated by the 2D:4D ratio) on targeting accuracy (dominant hand only), indicating that men exposed to a relatively high prenatal T/E ratio targeted significantly less accurately than men exposed to a relatively low prenatal T/E ratio. Our results for the male sample also demonstrated a significant main effect of circulating T concentrations on targeting

accuracy with the dominant hand, indicating that men with relatively high circulating T concentrations targeted significantly less accurately than men with relatively low circulating T concentrations.

However, we found a significant interaction between prenatal exposure to sex hormones and circulating T concentrations for targeting accuracy with the dominant hand that superseded the aforementioned results. A post hoc analysis of this interaction indicated that men who were exposed to a relatively high prenatal T/E ratio and who continue to have relatively high circulating T concentrations targeted significantly less accurately than all other groups of men. This finding is novel, as no previous study has examined the effects of both prenatal hormone exposure and circulating T concentrations on targeting accuracy.

Our finding that men with relatively high circulating T concentrations targeted significantly less accurately than men with relatively low circulating T concentrations supports our fifth hypothesis and is congruent with the significant findings of Janowsky et al. (1998). However, our finding indicating that men exposed to a relatively high prenatal T/E ratio targeted significantly poorer than men exposed to a relatively low prenatal T/E ratio did not support our second hypothesis regarding prenatal hormone exposure in men, which was made based on the findings of Sanders and Kadam (2001). Numerous possible explanations exist for the discrepancy in findings between our study and the study of Sanders and Kadam.

The discrepancy in findings between our study and the study of Sanders and Kadam (2001) may be explained by the fact that we utilized a different prenatal hormone estimator than they did. In the present study we used the 2D:4D ratio to estimate relative prenatal T/E ratios, whereas Sanders and Kadam utilized FRC asymmetry as an estimator of relative prenatal T concentrations. Thus, the discrepancy in findings may be because we are accounting for the ratio between prenatal T and E, whereas the Sanders and Kadam's estimator is thought to reflect only prenatal T concentrations. It may be that the T/E ratio is more important in prenatal development than are absolute T concentrations.

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Alternately, the discrepancy between our findings and those of Sanders and Kadam (2001) may be because our estimator (i.e., the 2D:4D ratio) is reflective of prenatal hormone concentrations prior to the 14th week of gestation (Garn, Burdi, & Babler, 1975), whereas their estimator (i.e., FRC asymmetry) is thought to be reflective of prenatal T concentrations prior to the 16th week of gestation (Jamison, 1990; Kimura & Carson, 1995). Thus the discrepancy in findings may be due to the slightly different timeline of development for the 2D:4D ratio and FRC asymmetry, meaning that prenatal hormone concentrations may change between the time in which the 2D:4D ratio is set and the time in which the FRC asymmetry is set. However, this possible explanation for the discrepancy in results is not a likely explanation, given that Lutchmaya and colleagues (2004) found the 2D:4D ratio to be related to prenatal T/E ratios during the 2nd trimester, which is past the time when the 2D:4D ratio has stabilized, but during the time in which the FRC asymmetry is developing and stabilizing. Thus it does not seem likely that prenatal hormone concentrations change drastically or quickly enough for the 2D:4D ratio and the FRC asymmetry to be differentially affected, and to thus be differentially related to targeting accuracy.

The most likely explanation for why our results differ from Sanders and Kadam (2001) is the differences in age between the samples, and the interactive effect that the organizational and activational periods of hormone exposure have on targeting accuracy. Sanders and Kadam's study involved a prepubescent sample that reflected differences in exposure to sex hormones prenatally, an organizational effect, but was not yet affected by circulating levels of sex hormones, an activational effect. Our study used an adult sample that presumably reflected both organizational and activational effects. Our main effects of both prenatal T/E ratios and circulating T concentrations were superseded by the interaction of these two effects, suggesting that one should not examine the effects of one period of hormone exposure (i.e., organizational) without examining the other (i.e., activational). Sanders and Kadam used a sample of prepubescent boys who were not yet affected by dimorphic circulating levels of

sex hormones, thus our data suggest that their sample's targeting accuracy may have changed upon reaching puberty. In other words, although prepubescent boys who were prenatally exposed to relatively high concentrations of T may target more accurately than prepubescent boys who were prenatally exposed to relatively low concentrations of T, this advantage may change upon entering puberty, when activational effects of sex hormones become evident. A longitudinal study conducted pre- and post-puberty which examines the relations among targeting accuracy and both activational and organizational periods of sex hormone exposure would best address this hypothesis.

The Effects of Prenatal Hormone Exposure, Menstrual Phase and Oral Contraceptive Use on Targeting Accuracy in Women

Our results for the female sample demonstrated a significant main effect of prenatal exposure to sex hormones (as indicated by the 2D:4D ratio) on targeting accuracy (non-dominant hand only), indicating that women exposed to a relatively low prenatal T/E ratio targeted significantly less accurately than women exposed to a relatively high prenatal T/E ratio. This result supports our second hypothesis, and is consistent with the findings of Sanders and Kadam (2001) and Hines and colleagues (2003).

Results for the female sample did not demonstrate significant main effects of either menstrual phase or oral contraceptive use. As such, our third hypothesis based on the findings of Saucier and Kimura (1998) and Janowsky et al. (1998), and our fourth hypothesis based on the findings of Janowsky et al. were not supported. This discrepancy in results between the aforementioned studies and our own results may be due to the fact that we included both OC and NoOC women in our sample, whereas the samples of Janowsky et al. and Saucier and Kimura consisted of NoOC women.

Our results did, however, demonstrate a significant menstrual phase by oral contraceptive use interaction for targeting accuracy with the non-dominant hand. This interaction indicated that women using oral contraceptives targeted significantly more accurately at the menstrual phase (no pill phase) compared to the midluteal phase (while taking pills); while no significant phase differences

were observed in naturally cycling women. This difference in targeting accuracy between the midluteal and menstrual phase in OC women may be due to a low estrogen concentration during the menstrual phase, a period in which no exogenous estrogens are being taken. This explanation is congruent with the findings of both Janowsky et al. and Saucier and Kimura, who found that low circulating E concentrations were associated with better targeting accuracy with the non-dominant hand in their samples of NoOC women, although we did not replicate this effect in our NoOC women.

Alternately, the difference in targeting accuracy between the midluteal and menstrual phase in OC women may be due to suppressed circulating unbound T concentrations during the midluteal phase, owing to exogenous estrogen supplementation (van der Vange et al., 1990). This explanation is incongruent with the findings of Janowsky et al., who found that low circulating T concentrations were associated with better targeting accuracy with the non-dominant hand in NoOC women. However, because we were unable to assay circulating hormone concentrations in our female sample, we are unable to differentiate between the possible activational effects of T and exogenous estrogen on targeting accuracy in our sample of OC women.

Integrated Discussion and Future Directions

Collectively the results indicate that men's and women's targeting accuracy is affected by both organizational and activational periods of exposure to sex hormones. The results suggest that there is an optimal level of prenatal T concentrations (or an optimal T/E ratio) that facilitates targeting accuracy in men and women. Exposure to relatively low concentrations of T prenatally (or perhaps a low prenatal T/E ratio) appears to facilitate targeting accuracy in men, whereas exposure to relatively high concentrations of T prenatally (or perhaps a high prenatal T/E ratio) appears to facilitate targeting accuracy in women. However, our interaction between organizational and activational hormone effects on targeting accuracy in men indicated that it is really the activational hormones that determine whether the organizational hormones will have an adverse effect on targeting accuracy. In men, targeting accuracy is only impaired if a man is

exposed to a relatively high prenatal T/E ratio and continues to have relatively high circulating T concentrations. In normal women who were presumably exposed to relatively low prenatal androgen concentrations compared to men and CAH women, we only observed activational effects of hormones on targeting accuracy in our sub-sample that were artificially raising their estrogen concentrations (and consequently artificially suppressing their circulating bioactive T concentrations) by using oral contraceptives. Thus it appears that relatively high concentrations of circulating T in men, and relatively high circulating concentrations of exogenous estrogen (or potentially artificially suppressed circulating T concentrations) in women, adversely affects targeting accuracy when organizational hormones have set the stage for the later activational effects.

There are numerous brain structures that likely underlie targeting accuracy: the visual system, for target localization; the parietal cortex, for the integration of spatial and motor knowledge (Goodale, Milner, Jakobson, & Carey, 1991); the primary and secondary motor cortices, for planning and initiating the motor command; the cerebellum, for integrating proprioceptive input from the body, coordinating movement, and timing (for review see Katz & Steinmetz, 2002); and the basal ganglia, for the smooth execution of the motor movement (e.g., Phillips, Bradshaw, Iansek, & Chiu, 1993).Given the vast number of brain structures that are assumed to underlie targeting skill, it is difficult to know which structures are differentially affected by organizational and activational sex hormones to produce the resultant sex difference. Future studies should use imaging techniques to attempt to examine how differences in relative prenatal exposure to sex hormones are related to functional and structural differences in brain regions underlying targeting accuracy (both within and between sexes), as well as examining how differences in circulating sex hormones concentrations are related to functional differences (again, both within and between sexes). Future studies could also address some of the limitations of this study, by using amniocentesis as a means of determining prenatal exposure to sex hormones instead of using a prenatal hormone estimator (i.e., the 2D:4D ratio), as well as by

using blood assays to determine circulating hormone concentrations in women instead of using menstrual phase and oral contraceptive use to estimate relative hormone concentrations in women.

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Figure Captions

Figure 1.   The interaction in men between right hand 2D:4D ratio and circulating T concentrations on targeting accuracy with the right (dominant) hand. Values are means +/- SEM.

Figure 2.   The interaction in women between menstrual phase groups and oral contraceptive use groups on targeting accuracy with the left (non-dominant) hand. Values are means +/- SEM.
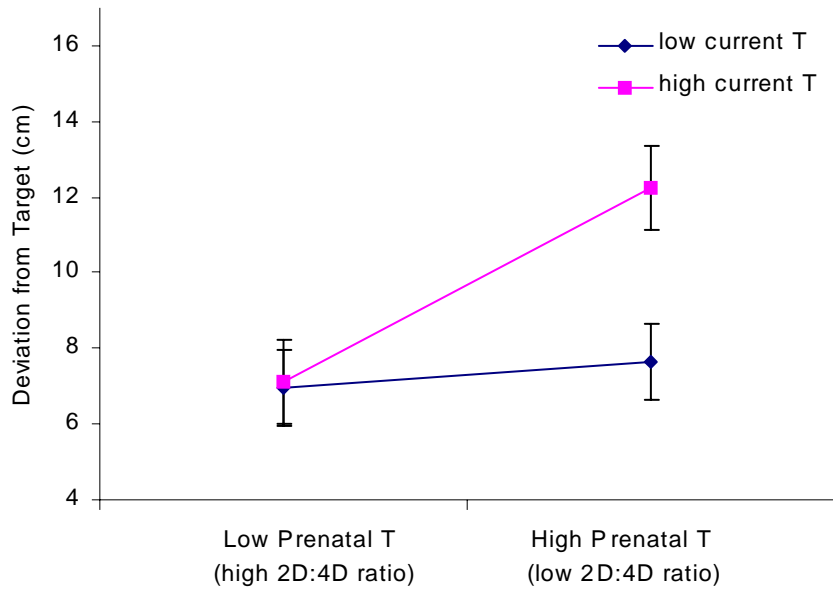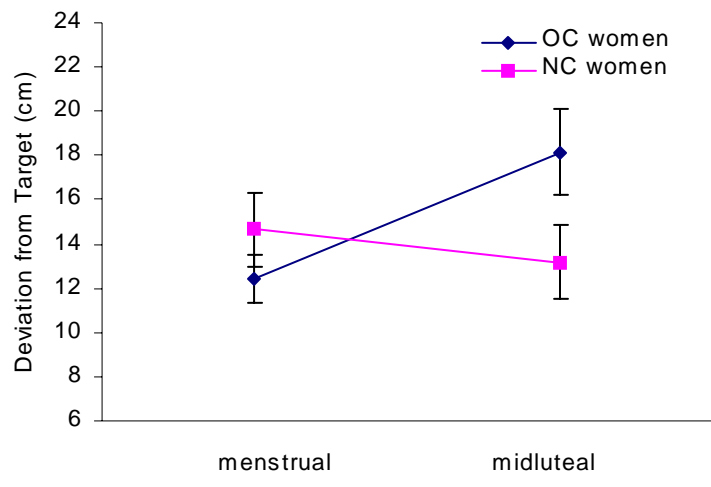
General Discussion

The purpose of this dissertation was to investigate the role of two sets of factors that are thought to potentially affect the sex difference observed on targeting tasks. Specifically, in Studies 1 and 2, I examined the effect that proxemic and motoric characteristics have on the typically observed male advantage on targeting tasks. In Study 3, I examined the relations among direct and indirect measures of organizational and activational sex hormones and targeting accuracy, within samples of men and women.

Studies 1 and 2

Studies 1 and 2 were based on a theory that was put forth by Kimura and colleagues that proposes that the male advantage typically observed on targeting tasks and the female advantage typically observed on fine motor tasks result from a sexually dimorphic organization of the praxic system (Chipman et al., 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991). This theory proposes that the more posteriorly localized organization of the male praxic system (which includes the dorsal visual stream in the posterior parietal cortex; Goodale et al., 1991) allows for enhanced integration of visuospatial information with motor commands, which in turn allows for enhanced "extrapersonal spatiomotor accuracy" (Watson & Kimura, 1991, 383). Conversely, the more anteriorly located female praxic system allows for enhanced skill on fine motor tasks and tasks involving "intrapersonal motor accuracy" (Hall & Kimura, 1995; Watson & Kimura, 1991, 383). Thus, the male advantage on targeting tasks may result simply from the typical task characteristics (i.e., performed using predominantly gross motor movements, directed at extrapersonal space), and not from an underlying advantage in aiming accuracy, per se. This hypothesis was examined in Studies 1 and 2 by manipulating the proxemic and motoric characteristics of numerous targeting tasks. I found that the male advantage on targeting accuracy was negated only on a targeting task that was performed in intrapersonal space and involved only fine motor movements. As such, my findings are congruent with the theory put forth by Kimura and colleagues.

I was, however, unable to address the part of the theory put forth by Kimura and colleagues that attributes these sex differences to the sexual dimorphic organization of the praxic system (Chipman et al., 2002; Hall & Kimura, 1995; Kimura, 1983; Kimura, 1993; Watson & Kimura, 1991). Future studies could be performed using functional magnetic resonance imaging (fMRI) to examine whether there are differences in the area and amount of brain activation in male and female participants who are performing comparable gross and fine motor tasks performed in intrapersonal and extrapersonal space (such as the targeting tasks used in Study 2). Alternatively, future studies could examine whether transcranial magnetic stimulation (TMS), when applied to motor regions anterior and posterior to the central sulcus, selectively interferes with intrapersonal and extrapersonal motor tasks and/or fine and gross motor tasks, respectively. This TMS experiment should also examine whether there is a sex difference in the pattern of motor interference produced by the stimulation.

Further, it should be noted that other task characteristics may also mediate the sex difference observed on gross and fine motor tasks performed in intrapersonal and extrapersonal space. For instance, Chipman and colleagues (2002) found that men showed a significantly larger decline in performance than women when vision was occluded on two intrapersonal gross motor tasks (i.e., the manual sequence box and the sequential arm tapping task). This finding implies that men are more reliant on their visual system when performing tasks that are largely praxic in nature, which need minimal visual cues. Further, this finding may imply that the posteriorly located praxic system in men may make them more adept at performing motor tasks that are critically reliant on visual processing, such as targeting accuracy and the interception of projectiles (both of which demonstrate a male advantage; Watson & Kimura, 1991).

Alternatively it may be that is a male advantage on extrapersonal tasks, such as targeting, while there is a female advantage on intrapersonal tasks, such as the PP (Tiffin, 1968) and the Barrel and Debu (2004) targeting task (involving contact between the target and the participant's finger), because they differ in whether there is sensory feedback during the task that allows for correction of the

motor movements after they have been initiated. That is, once the motor movements associated with targeting have been initiated, there is no chance for on-line correction; it is an open-loop task. On the other hand, performance on the PP requires direct contact with the target, as such there is on-line correction until the task is complete; it is a close-loop task. To speculate, it may be that the open-loop nature of targeting tasks facilitates male performance via the requirement for precise timing. There is a very small window of time during which the ball needs to be released on an overhand targeting task in order to achieve accuracy; Hore and colleagues (1995) found this window to be 9.6 msec on average in male professional athletes (n.b., women were not tested). It may be that men demonstrate an advantage on the precise timing of ball release during targeting tasks, thus facilitating their accuracy; conversely, the PP may demonstrate a female advantage because it is a closed-loop task that provides sensory feedback to facilitate the timing of peg release.

Another difference between male advantaged targeting tasks and females advantaged fine motor intrapersonal tasks, such as the PP and the Barral and Debu targeting task (2004), is the requirement of aiming accuracy versus both speed and aiming accuracy, respectively. Thus, it may be the speeded nature of these tasks that accounts for the female advantage. Support for this hypothesis comes from Nicholson and Kimura (1996) who demonstrated that women outperform men on the repetition of a sequence of manual movements when baseline motor speed is accounted for.

Study 3

Study 3 examined the relations among prenatal exposure to sex hormones, circulating sex hormone concentrations, and targeting accuracy within samples of men and women. The results from Study 3 appear to indicate that both exposure to high prenatal T/E concentrations and high circulating T concentrations are associated with poor targeting accuracy in men. Specifically, men who were exposed to relatively high prenatal T/E concentrations and who had relatively high circulating T concentrations in adulthood performed significantly poorer on a targeting task than: men who were exposed to relatively high prenatal T/E

concentrations but now have relatively low circulating T concentrations, and men who were exposed to relatively low prenatal T/E concentrations, regardless of circulating T concentrations.

In women, again I found that both prenatal and circulating sex hormones affected targeting accuracy. Specifically I found that women who were exposed to relatively low prenatal T/E concentrations targeted significantly more accurately than women who were exposed to relatively high prenatal T/E concentrations. Furthermore, the women that were taking oral contraceptives that were at the midluteal phase of their menstrual cycle targeted significantly less accurately than women taking oral contraceptives who were at the menstrual phase of their cycle. However, these results are somewhat problematic as I found a significant effect of circulating hormone concentrations (an activational effect) in my sample of women who were taking exogenous hormone supplements (i.e., oral contraceptives), but not in the sample of naturally cycling women. This finding is incongruent with previous reports (Janowsky et al., 1998; Saucier & Kimura, 1998). It is likely the case that I was unable to find a similar effect in the naturally cycling women because I was using an indirect estimator of relative hormone concentrations (i.e., menstrual phase), whereas the previous reports used direct measures (i.e., assays) (Janowsky et al., 1998; Saucier & Kimura, 1998). Further, because the activational hormonal effect was observed using an indirect measure in the sample of OC women, I was unable to determine whether the menstrual phase effect was due to lower E concentrations, or whether it was due to the circulating unbound T concentrations no longer being artificially suppressed (van der Vange et al., 1990).

Overall, the results of Study 3 appear to indicate that both organizational and activational sex hormones influence targeting accuracy in men and women. It appears that both relatively low and high prenatal T or T/E concentrations are associated with poor targeting accuracy across the sexes; with relatively high prenatal T or T/E concentrations being associated with enhanced targeting accuracy in women, and relatively low prenatal T/E concentrations being associated with enhanced targeting accuracy in men. Relatively high circulating T

concentrations may also be needed in order for targeting accuracy to be adversely affected in men; whereas relatively high circulating T concentrations may be associated with enhanced targeting accuracy in women (as indicated by the finding of enhanced performance in OC women at the menstrual phase). However, further testing is required to confirm this relation. Ideally, future studies will further investigate the roles of organizational and activational sex hormones on targeting accuracy by using samples whose prenatal sex hormone environment is known (i.e., samples in which amniocentesis was performed during the second trimester, similar to Finegan, Niccols, & Sitarenios, 1992), and by using blood serum to determine the circulating sex hormone concentrations. Blood serum should be used to determine circulating sex hormone concentrations because previous research has demonstrated that salivary assays (both radioimmunoassay and enzyme immunoassay) and blood spots substantially underestimate testosterone-behaviour associations for free T (especially in women) (Shirtcliff, Granger, & Likos, 2002).

The Integrated Hypothesis

As stated in the Introduction, the two theories that this dissertation addressed were not mutually exclusive. Having found support for each of the theories, we can now consider an integrated hypothesis that was first put forth by Hall and Kimura (1995). Hall and Kimura proposed that prenatal exposure to sex hormones differentially affect either the neural circuitry underlying visuomotor control in intrapersonal and extrapersonal space, and/or the neural circuitry underlying gross and fine motor control, thereby resulting in the sex differences that are typically observed on targeting and fine motor tasks. The results from Studies 1 and 2 appear to indicate that the neural circuitry of both these systems are likely influenced by sex hormone concentrations, as proximity and motor type have an additive effect in negating the sex difference on targeting tasks. Further, the results from Study 3 (along with the findings of Janowsky et al., 1998, Hines et al., 2003, and Saucier & Kimura, 1998) appear to indicate that circulating sex hormone concentrations, as well as prenatal sex hormone concentrations, influence targeting accuracy in adult men and women. As such, one may propose

a further integrated hypothesis that includes a role for both prenatal and circulating sex hormone concentrations. In general, my findings, along with the findings of others (Janowsky et al., Hines et al., Saucier & Kimura), appear to indicate that there is a curvilinear relation between gross motor extrapersonal targeting tasks and T concentrations across the sexes, with high circulating and prenatal T concentrations in women and low circulating and prenatal T concentrations in men being associated with enhanced targeting accuracy. As such, the integrated hypothesis may predict that relatively high prenatal concentrations of T in women causes the development of a male typical posteriorly located praxic system that facilitates performance on gross motor tasks directed at extrapersonal space; this same system is then facilitated later in life by relatively high circulating T concentrations (or possibly relatively low circulating E concentrations). Alternatively, relatively low prenatal concentrations of T in women may result in the development of a female typical anteriorly located praxic system that facilitates performance on fine motor tasks performed in intrapersonal space; this same system may then be facilitated later in life by relatively low circulating T concentrations, or perhaps by relatively high circulating E concentrations as is suggested by Hampson and Kimura (1988) and Saucier and Kimura (1998). In men, the relations among prenatal and circulating T concentrations, praxic system organization, and praxic functioning are less clear. It appears that the combined exposure to relatively high prenatal and circulating T concentrations adversely affects male performance on gross motor extrapersonal targeting tasks. As such, relatively high prenatal T concentrations may result in an organization of the praxic system that does not facilitate performance on gross motor extrapersonal tasks, presumably then, one that is not posteriorly located; this same system is then adversely affected later in life by relatively high circulating T concentrations. Alternatively, it may be that exposure to relatively low prenatal T concentrations results in the development of a male typical posteriorly located praxic system that facilitates male performance on gross motor tasks directed at extrapersonal space; this system allows for enhanced

performance on extrapersonal gross motor tasks, regardless of whether circulating T concentrations are relatively low or high.

An Evolutionary Hypothesis Concerning the Association between Testosterone Concentrations and Targeting Accuracy

Because targeting is a relatively unique human ability that has been around for many years, many researchers have put forth evolutionary theories to explain the adaptational advantages of the skill (largely pertaining to hunting and defence) (e.g., Calvin, 1982; Kolakowski & Malina, 1974; Watson, 2001). Kimura and colleagues have also suggested that the sexually dimorphic organization of the praxic system may be due to the differential division of labour between men and women over the course of hominid evolution, in which men hunted and women gathered (Watson & Kimura, 1991).

As noted above, my findings along with the findings of others appear to suggest that there is a curvilinear relation across the sexes between both prenatal and circulating T (or perhaps T/E) concentrations. That is, enhanced targeting accuracy appears to be related to: exposure to high concentrations of T or T/E prenatally in women (Hines et al., 2003; and Study 3, respectively) and exposure to relatively low concentrations of T/E prenatally in men (Study 3); and high circulating T concentrations in women (Study 3- though further investigation is needed) and low circulating T concentrations in men (Janowsky et al., 1998; and Study 3). As such, there appears to be a curvilinear relationship between T concentrations and targeting accuracy across the sexes; such a relation has been previously reported for paper and pencil tasks of spatial ability and environmental spatial abilities (Bell & Saucier, 2004; Gouchie & Kimura, 1991; Moffat & Hampson, 1996).

The relation between high T concentrations and enhanced targeting accuracy makes sense in women, as numerous studies have found a relation between high T concentrations in women and male typical behaviours, abilities, and traits. For example, studies comparing women who were exposed to atypically high concentrations of T prenatally (due to CAH) to normal control women have found that women with CAH are: more interested in male-typical

and less interested in female-typical activities throughout the lifespan; more aggressive, but less empathetic and maternal (self-reports); less interested in infants (parent-reports); more likely to be sexually attracted to women (approximately 1/3 are lesbian or bisexual); and more likely to have better spatial abilities (though some studies have failed to find this difference) (for review see: Cohen-Bendahana, van de Beeka, & Berenbaum, 2005).

But why are relatively low T concentrations associated with enhanced targeting accuracy in men? In light of the evolutionary importance of targeting accuracy, the question remains as to why relatively low T concentrations would be associated with enhanced targeting accuracy in men, while higher T concentrations are associated with traits that are typically thought to be adaptive, such as muscle strength and size (e.g., Bhasin et al., 1996; Griggs et al., 1989). Of course, as is the case with any evolutionary theory, one can only speculate on the adaptive nature of such an association. It may have been the case that accurate targeting ability was naturally and sexually selected for in men with relatively low T concentrations. That is, given the relation between T concentrations and muscle size and strength, men with lower T concentrations were presumably smaller and weaker (e.g., Bhasin et al.; Griggs et al.). For these men who were smaller and weaker, targeting accuracy may have been a particularly adaptive trait as it would have allowed them a means of self-defence against larger men and against predatory animals (intrasexual selection, and natural selection, respectively). This would have also allowed them to excel at hunting, thus making them more desirable to a potential mate (intersexual selection). On the other hand, larger stronger men with presumably higher T concentrations would have been able to use their strength to aid their hunting and defence, which would have also been selected for. As such, this hypothesis proposes that there may have been a within sex division of labour or abilities throughout our evolutionary heritage, whereby large men were better fighters, and small men were better at targeting.

Interestingly, a within sex division of labour can be observed in current day in many sports that involve both targeting and defensive behaviours, such as football and hockey. Within these sports some individuals are responsible for

defence and fighting, whereas other players are responsible for offence, which requires them to throw, kick, or shoot accurately (i.e., targeting). Typically within these sports the offence players are comparatively smaller than the defence players (especially in football where quarterbacks and kickers are usually considerably smaller than the defensive line players). Although one can not test the evolutionary hypothesis regarding an adaptive relation between T concentrations and targeting accuracy, it would be an interesting study to examine the relations among size, T concentrations, and positions (offensive or defensive) within sports.

Practical Implications of the Current Research

By determining the factors that are responsible for the sex difference in targeting accuracy we can gain a greater understanding of the factors that influence individual differences in targeting accuracy overall, which may in turn enable us to work towards reducing these differences. In Study 1 and Study 2 of this dissertation it was concluded that the sex difference observed on targeting accuracy is affected by the proxemic and motoric task characteristics. Although it is not feasible to turn all targeting tasks found in sport, hunting, and policing into intrapersonal fine motor targeting tasks that would no longer demonstrate a sex difference, one may be able to use these findings in training to lessen the sex difference on typical targeting tasks. For example, it may be advantageous for individuals who are poor at targeting accuracy to learn a new targeting task first within intrapersonal space and then progressively increase their distance from the target once high levels of accuracy and confidence have been achieved. Another possible application of these findings could be to build a scope into all guns that are used by law enforcement officials, so that the proxemic domain of the target appears closer, allowing for enhanced targeting accuracy in those who do not typically excel on targeting tasks. Although some researchers have demonstrated a male advantage on shooting accuracy (e.g., Boyce, 1992; however others have failed to demonstrate this sex difference- see Boyce, 1987 & 1990; Kemnitz et al., 2001), there have not been any studies examining whether a scope on a gun

differentially advantages male and female shooters. This would be another future study to consider.

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