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MENTAL ACROBATICS: SPATIAL PERCEPTIONS OF HUMAN ROTATION

BY

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DISSERTATION

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## ABSTRACT

The primary goal of this dissertation was to understand to what extent are humans capable of accurately perceiving both their own rotations and the rotations of others and how do spatial manipulations of the actor and the perceiver affect the perception of the action. Four experiments were conducted. Experiment 1 examined the perceptual abilities of both expert gymnasts and novices in the accurate judgment of either a left or right rotation by an animated human figure (avatar) in a series of fixed picture plane orientations. Participants responded with either a verbal “left” or “right” and their mean accuracy and mean response time were recorded. Experiment 2 used the same stimulus but the participants were asked to report their answers by way of one of four arrow button combinations; right button corresponded to a right twist, left button corresponded to a right twist, up button corresponded to a right twist and down button corresponded to a right twist. Both mean accuracy and response time were recorded for each group. Experiment 3 mirrored Experiment 1 except the participants were randomly fixed in one of six picture plane orientations from  $0^{\circ}$  to  $300^{\circ}$  of rotation. Experiment 4 used the same apparatus as Experiment 3 where the participants were randomly placed in one of six picture plane orientations however the participants were rotated either left or right and were asked to verbally report their own twisting direction. Experiment 4 tested both novices and expert gymnasts.

The general results suggest that the task of accurately determining the twisting direction of another human form is challenging and cognitively demanding. Under most conditions accuracy decreased and response time increased as the phase angle between the participant and the avatar approached  $180^{\circ}$ . In Experiment 1 experts and novices performed the same and were least accurate and took the longest to respond when the avatar was inverted. The results from

Experiment 2 suggested a conflict of strategies between the constraints of the task and the inherent challenge of the task. Participants in Experiment 3 were generally uninfluenced by their own picture plane orientation and in almost all combinations of participant and avatar picture plane orientation they were more accurate and faster than the exclusively upright participants in Experiment 1. The experts in Experiment 4 were flawless in their responses and significantly faster than in any other experiment. The novices were also relatively fast but the accuracy of the judgments on their own twisting directions was no better than the participants watching the avatar in Experiment 1.

The findings suggest that the general task of determining human rotation as either a left or right turn is so challenging that a number of conflicting strategies may have been employed by the participants to help lessen the cognitive demands of the task. The data speaks to the specificity of expertise and outlines a potential discrepancy between expert observers and expert performers. The data suggests that the use of an internal reference frame during the spatial perception of biological motion may be consistent across conditions regardless of participant orientation.

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## INTRODUCTION

Accurate visual perception of human movement may be one of the most important social tools an individual can have. Physical movement of the human being contains such subtlety and diversity that even a lifetime of study would not reveal a precise classification of elemental action. Yet as an observer, biological motion is so profoundly singular that it is immediately distinguishable from other inanimate motion. Although all objects, biological or not, must rely on the same set of physical laws to move, human beings can think, learn and respond dynamically and therefore move in such complex and distinctive ways that there exists the potential for a wealth of information to be conveyed to the observer. Human beings are inherently social creatures and this fundamental ability may indeed play such a reflective role in the nature of our being that propagation and survival would not exist in its absence.

It has been argued that the cognitive processes that are developed from early in life are the same for dealing with the physical world as they are for dealing with the social world (Piaget, 1954). Having the capacity to distinguish between animate and inanimate action is paramount to this connection. Nevertheless the potency of this synergy has since been downplayed and perceptual facilities have been argued to be much more domain specific (Gelman & Spelke, 1981). Human's potentially innate ability in the perception of biological motion has been revealed in children as young as 9 weeks old, where through physical action the infants were adept at discriminating between human movement, humans in the absence of movement, and inanimate objects (Legerstee, Corter, & Kienapple, 1990). A number of researchers suggest that this ability provides a basic survival function (Giese & Poggio, 2003; Ikeda, Blake, & Watanabe, 2005; Jokisch & Troje, 2003; Thornton & Voun, 2004). Being able to accurately perceive specific biological motion cues provides a means of recognition of both friend and foe from a

distance. Understanding the spatial orientation and direction of such movements may facilitate appropriate defensive actions. Accurately perceiving biological motion is also critical in the learning of both rudimentary and complex motor tasks. Because the majority of skills we learn are through observation, accurate perception of that motor skill is a valuable commodity not only during child development but throughout life (van Gog, Paas, Marcus, Ayres, & Sweller, 2009).

So unique is movement of the animate and so acute is our ability to perceive such movement that its intrigue has been evident throughout history:

The movements of animals differ so strikingly from the movements of inanimate objects that throughout most of the history of analytical thought about natural phenomena it was taken virtually for granted that these movements betrayed the presence of processes of a nonphysical nature. The very term animal derives from the Greek word *animos*, by way of Latin *anima*. The original Greek meaning was “wind.” Greek and Latin philosophers used the word to refer to some active but unsubstantial principle or aspect of reality that was present in “animals” but absent from the ordinary objects of the physical world.

(Gallistel, 1980, p. 1).

Indeed, scholarship related to perceiving human movement was prevalent in thought even during the time of Aristotle: “Thus it is clearly reasonable that progression be the last movement which occurs in generated things; for the animal moves itself and progresses by intention or choice, when some alteration has occurred in accordance with perception or imagination.”

(Preus, 1981, p. 33).

Perhaps one of the earliest great contributions to the field of perception and analysis of biological motion is the extensive photographic work of Muybridge (1901). During his tenure at the University of Pennsylvania in the late 1800’s he constructed over 20,000 photographs on the

movements of humans and animals including gait patterns, turns, and basic human tasks.

Because of the technique he developed to take a series of photographs in rapid succession, he is considered by many to be the “father of the motion picture” (MacDonnell, 1972). Many of his photographs are still used for research and educational purposes today. His impact on the study of biological motion perception was largely in the development of tools that allowed researchers to be able to view static phases of movements that would otherwise be continuous. For the first time it was possible to study the relationship between the observers visual perception of the action and the actual kinematics of the action being perceived.

Aspects of the classical thought that biological motion embodied some dynamic and ethereal element my still be inexplicably relevant today. Consider the movements of early hand drawn animated figures to that of the computer generated animated figures in modern films. Before the advent of biological motion capture in movie, television, and video game animation, the kinematics of the animated figure lacked a certain indescribable likeness to the figure it was modeling. Even the early work of Cutting (1978) on generating synthetic walkers on a computer screen relied on the two-dimensional recordings of actual human walkers for appropriate manipulations of the kinematic parameters. Modern perceptual tasks rely heavily on the use of motion capture to reproduce the “unsubstantial principle” described by Gallistel (1980) in studies related to the perception of biological motion (Vanrie & Verfaillie, 2004).

Although this dissertation was an investigation of the perception of human movement, the spatial orientation of the actor and the observer were of particular importance. The fundamental idea was to understand to what extent the spatial orientation of either an actor or an observer affects the action being perceived from the perspective of either the actor or the observer. It is the particular cases in which the visual information available to the optic array is

unchanged with a change in orientation that was of interest. Under these conditions it may be possible to understand the role of one's spatial orientation on the perception of human movement.

To elicit such a condition the specific task was the observation of human rotation in a variety of spatial orientations. Rotation is a unique action in which motion cues relative to internal body segments are unchanged while the overall body is dynamic. Within human movement there exists a catalog of similar actions yet rotation about the vertical axis was preferred as it is regularly performed upright and in a variety of spatial orientations by figure skaters, gymnasts, snowboarders, aerial ski jumpers, and divers. The relationship between observer and actor was paramount and the specific action described provided a valuable contribution to the understanding of the spatial perception of biological motion and how that perception is influenced with changes in spatial orientation. The issue is best expressed anecdotally through a conversation with a male Olympic gymnast. During a discussion of his ring dismount, which involved multiple flips and multiple twists, the direction the athlete twisted was in question and a discrepancy between the observer and the gymnast was apparent. During right-side up conditions the athlete may have likely been aware of which way he was rotating yet when the spatial orientation of the body was manipulated because of the multiple flips in the air, the perception of the once apparent twisting direction became fraudulent. This particular issue transcends any single theoretical perspective and therefore is explored from a variety of standpoints to effectively understand the spatial and perceptual contributions.

Three distinct theoretical areas are examined starting with the most general and culminating with a focus on the spatial perception of the human form. All three areas focused on the use of the visual system in the perception of the environment. Dominant theories in visual

perception are explored initially with a focus on two distinct areas. The first was the ecological theory of direct perception originally proposed by Gibson (1950, 1966, 1979) where the primary conjecture is that all the information needed for accurate perception of the environment is directly evident through the collection of light sources available to the retina. In contrast a group of related theories that generally contradict Gibson's work are presented. A number of researchers have proposed the theory of indirect perception for the visual system where significant brain processes and prior experience of the environment are critical (Helmholtz, 1867; Koffka, 1935; Köhler & Wallach, 1944; Marr, 1982). This group of theories rejects the notion that only the dynamic array of light available to the retina is sufficient to accurately perceive the environment.

The second area of focus is the visual perception of specifically biological motion. This section is again approached from two areas. The first looked at the impact of Johansson's (1973) work on the perception of biological motion through the use of point-light display. Point-light display is the presentation of biological motion where only the head and major anatomical joints of the biological form are visible before a neutral background. It appears that a wealth of information is available to the observer solely on the relative motion of the joints in space. The second area that is briefly explored is the perception of intact biological motion either through the use of static pictures or movement of the entire human form, not just the spatial location of the anatomical joints.

The third theoretical area explored is an introduction to studies related to mental rotation strategies. The concept of being able to mentally rotate an object in space was initially proposed in the seminal work of Shepard and Metzler (1971) where participants reported changing the orientation of a three-dimensional object in their mind in order to successfully complete an

object matching task. Not only was the notion of a mental representation of a three-dimensional object proposed, but the idea that human's have the ability to mentally manipulate such a representation was ground-breaking. Save the perception of faces, a limited number of studies have explored the mental rotation of the human form. Included in this summary is the theory of embodied spatial rotations where the supposition is that under particular conditions the observer actually performs a mental rotation of their own body or body parts to a more favorable orientation. Because of the fairly undeveloped field of the spatial perception of biological motion the well established areas of research previously mentioned provide a thorough framework for the line of questioning outlined.

### Theories of Visual Perception

There are two dominant contrasting theories related to visual perception where the crux of the disagreement is in the role that cognition and higher brain functions play in the recognition of objects and movements. These theories are often ministered as mutually exclusive yet some researchers prescribe aspects of both into their investigations. The ecological approach championed by Gibson (1950, 1966, 1979) provides a distinctly unique theory where the role of higher brain function is generally absent during visual perception. A fundamental aspect of the theory is that the environment singularly defines what the person can perceive and there is a direct link between the perception and the action of the observer. In contrast, the competing theories provide an avenue where cognition is vital to the perceptual process. A number of researchers have unique perspectives on this theory but a consistent component is that the perceptual process is not direct, i.e. retina to response, and the differences in the theories focus on the manner in which cognition is employed as a component of the indirect process.

Two theories related to indirect perception have influenced a majority of examinations related to the role of cognition in visual perception. The inferential approach proposed by Helmholtz (1867) suggests that perception is primarily a thought process where the observer must infer what the object or the action is based on the most likely possibility determined by the individual's experiences. The supposition is that considerable data gets lost in the projection of a three-dimensional world onto the two-dimensional surface of the retina. To recover the missing data, the observer generates the most probable real-life interpretation based on the array of light stimulating the retina at that time. It is proposed that the accuracy of the selection is based on the individual's past experiences and possibly some inborn evolutionary components. When the added information is correct the observer perceives the veridical and when the added information produces a wrong interpretation, the observer perceives an illusion. The strength of the theory lies in the ability to predict the nature of the illusion perceived. Consider the line drawing in Figure 1. Most people will perceive the drawing as an angled perspective of a three-dimensional house with a roof and a door. The actual interpretation is not known and the line drawing could in fact be just a series of skewed lines that connect. The inferential approach to visual perception would suggest that the perception of a house occurs because it is the most probable interpretation based on experiences viewing a three-dimensional world and the data provided. Modern computational theories of vision (e.g., Marr, 1982) are closely tied to the inferential approach as heuristic assumptions must be made in order to reconstruct the lost data in the projection from a three-dimensional world to a two-dimensional acquisition (Palmer, 1997). One of the challenges of the theory is the rationale behind the most probable interpretation. This is not easily resolved. Rock (1977, 1983, 1997) has written extensively on this particular issue as well as the inferential approach in general.

As a distinction from the inferential approach, the organizational approach (Koffka, 1935; Köhler & Wallach, 1944) is also invested in the responsibility of cognition, but instead of the individual selecting the most probable interpretation, the perceiver adds to the insufficient information from the retina by evaluating the inherent structure of possible interpretations. Similar to the inferential approach, a basic assumption is that data is lost in the projection from a three-dimensional world onto the two-dimensional surface of the retina but instead of adding data based on the most probable interpretation, the organizational approach suggests that data is added to perceive the best interpretation. In most cases the term “best” is described as the interpretation with the simplest, most regular, and most symmetrical structure (Palmer, 1997). Based on the organizational approach, when the real world image is the simplest, most regular, and most symmetrical structure then the observer will perceive the veridical and in the case that it is not, the observer will perceive an illusion. This approach has a different interpretation of why the majority of people will view the line drawing in Figure 1 as a house. The deduction is that the perception of a house with a roof and a door is the best interpretation given the provided information. With this example it is hard to distinguish between the two theoretical perspectives because in the majority of the cases, the best interpretation is also the most probable. It is mainly when people perceive an illusion instead of the veridical where the subtleties of the approaches are highlighted. A deficit of the organizational approach is similar to that of the inferential approach and is in the interpretation of the term “best.” In a number of cases this produces a circular logic as the best perceptual interpretation is the one used, however, the interpretation used was done so because it was the best.

In stark contrast to the indirect perceptual approaches outlined, Gibson’s ecological approach to direct perception assumes that all of the information required to interpret the world

being viewed is available to the retina. The distinction is clearly stated in the title of Mace's 1977 text on direct perception: "Ask not what's inside your head, but what your head's inside of" (p. 43). There are three main assumptions to the ecological approach and the primary is that the array of light stimulating the retina is sufficient for accurate perception and no additional unconscious inferences or organizations are required to reconstruct lost data. Gibson suggests that all of the information required is in the texture gradients of the world being viewed. He defines texture gradients as a surface pattern containing form, distance, and depth cues from the environment. One of Gibson's greatest contributions to the field of visual perception is the demonstration that the array of light stimulating the retina is incredibly rich with data. The second assumption is that perception is natural and immediate and therefore again, no additional unconscious inferences are required. This assumption is reinforced by the spontaneous recognition of human movement patterns from a series of dots on a planer surface (e.g., Johansson, 1973) which will be subsequently reviewed in detail. The third assumption is that perception and action are inherently linked and perception provides guidance for action and action allows for accurate perception of the environment. Based on the third assumption the ecological approach has a unique interpretation of why the majority people will view the line drawing in Figure 1 as a house. During active exploration of the environment, which is critical based on the assumed link between perception and action, the observer will determine that the depth information is embedded in the relative positions of each of the lines and will perceive the veridical. A number of problems arise with this, not the least of which is how does an individual accurately perceive the line drawing of the house without being able to move around it? Also Gibson only loosely outlined how the brain actually deals with the retinal information only to suggest that no internal knowledge about the world was required.

### Perception of Biological Motion

Although the theories related to visual perception can provide perspectives on how the human being recognizes what is visible to the retina, the perception of movement and more specifically the perception of biological movement requires a more focused review to understand the salience of specific cues. The importance of Muybridge's work in the visual display of human and animal movement is indisputable yet during the same time, working independently in France, Etienne-Jules Marey developed a similar system to accurately capture movement at a high rate of speed. Marey's photographic techniques were the end result of a series of attempts to capture the kinematics of human movement with a technique he named "chronography" (Marey, 1878). Although the device was useful for such things as recording the timing of footfalls during gait, Marey quickly understood the importance of being able to capture movement visually. The result was a device similar to that of Muybridge's except all of the images were overlaid on a single negative. The work of Marey was so profound that it is suggested that the majority of modern time-scale recording devices such as oscilloscopes and electromyography were based on his designs (Ashley-Ross & Gillis, 2002).

The action of the human or animal in the images of either Muybridge or Marey are immediately noticeable even though the observer is only viewing a series of static images. Furthermore it has been shown that the display of two static pictures of a person performing an action is adequate in rendering the perception of motion (Heptulla-Chatterjee, Freyd, & Shiffrar, 1996). Initial research suggested that the apparent motion was solely due to parameters related to time and distance and the nature of the structure of the object was insignificant (Kolars & Pomerantz, 1971; Shepard, 1984). The more recent contention is that the apparent motion is

highly dependent on the structure of the object as long as that structure has inherent kinematic constraints, such as with the joint angles of a human (Shiffrar & Freyd, 1990). When biological forms were presented the perceived motion was defined by two parameters; the anatomical possibility of the action and the shortest distance of travel within the anatomical constraints. Although there is a raft of evidence to suggest that the perception of biological motion is dependent on the form being observed, the motion perceived is apparent but not veridical as no continuous stream of movement stimulates the retina.

The culmination in the contribution of Marey (1878) was the visual display of the spatial and temporal locations of the anatomical joints of the biological system being photographed. Johansson (1973) borrowed primarily from this idea in the development of point-light display. Point-light display is the cinemagraphic or video recordings of a human figure where only the head position and major anatomical joints of the body are visible. This is usually achieved by recording a performer with either reflective markers or active lights attached to the joints of a performer in front of a black background. In essence what is recorded is an array of point-light sources moving on the visual display. Static images of point-light display often appear meaningless or void of veridical information, yet when the point-lights move in an appropriate fashion, even the naïve observer has no trouble perceiving the action generated by the actor (e.g., Dittrich, 1993; Norman, Payton, Long, & Hawkes, 2004). The vivid impressions of point-light display is apparent and Johansson outlined a visual vector analysis model to explain the vividness of the impression of 10 dots moving on a screen that reveal walking to the observer. His analysis is rather geometric and mathematical and focuses very little on the underlying structure of the actor and the perceptual experiences of the observer.

Observing only the head and major joint locations of an actor on a two-dimensional plane provides a wealth of information beyond just the recognition of the action and it has been proposed that the power of such observations is a function of the relative kinematics of one joint with respect to another (Cutting & Kozlowski, 1977). Indeed the early work of Cutting and Kozlowski was a direct consequence of the work of Johansson (1973, 1975) and particularly with his point-light films (Maas, Johansson, Jansson, & Runeson, 1970, 1971). Using point-light display, Cutting and Kozlowski showed that observers were able to accurately identify friends by their walk in the absence of familiarity cues. More recently Troje, Westhoff, and Lavrov (2005) have replicated to findings of Cutting and Kozlowski. In a related work Kozlowski and Cutting (1977, 1978) also showed that observers could accurately identify the sex of the walker from the point-light display although observations were not necessarily perfect (Pollick, Kay, Heim, & Stringer, 2005). This too has been verified with a number of more contemporary studies (Mather & Murdoch, 1994; Sumi, 2000 & Troje 2002). When observing point-light display, observers are adept at judging the emotional implications and goals of the actor (Clarke, Bradshaw, Field, Hampson, & Ross, 2005; Dittrich, Troscianko, Lea, & Morgan, 1996; Walk & Homan 1984). This has been shown with specific light placements on just the face as well (Bassili, 1978). Although only the relative kinematics is being displayed, observers can accurately estimate the weight of a lifted object from only the lifting action (Bingham, 1993). Possibly even more insightful, people can also accurately determine the effort required in lifting from just the point-light display (Shim, Carlton, & Kim, 2004). Other kinetic parameters such as the elasticity of a support surface the actor is walking on can also be determined (Stoffregen & Flynn, 1994).

The perception of biological motion is remarkably robust (Blake & Shiffrar, 2006) and the sensitivity to human motion with point light display can be exploited depending on the

severity of the manipulation performed in either a spatial or temporal domain. Accurate motion can be perceived with less than one-tenth of a second of stimulus (Johansson, 1973) but in general manipulations in the temporal domain severely disrupt the observer's abilities (Bertenthal & Pinto, 1993). The characteristics of the human motion perceived can be easily manipulated by establishing jitter into the phase relations of the point-light display (e.g. Grossman & Blake 1999). Also, embedding temporal noise greatly impacts accurate detection of the biological action (Hiris, Krebeck, Edmonds, & Stout, 2005). The majority of spatial manipulations performed have a lesser impact on the perceptual accuracy of the action where in extreme cases particular markers are blurred or even randomized and the observer is still effective at recognizing the action (Mather, Radford, & West, 1992). This is also true when the three-dimensional projection of the marker locations on the two-dimensional surface viewed by the observer is relocated in the depth plane (Ahlstrom, Blake, & Ahlstrom, 1997; Lu, Tjan, & Liu, 2006). People can accurately recognize the point-light action even when the point-light markers are implanted with a host of randomized dots on the screen (Bertenthal & Pinto 1994; Cutting, Moore, & Morrison, 1988; Ikeda, Blake, & Watanabe, 2005). Although the cues are most compelling when the markers are placed on the anatomical joints, accurate perception is still possible when the joint markers are replaced with markers located mid-limb (Bertenthal & Pinto, 1994). It has been recommended by Pinto and Shiffrar (1999) that markers on the elbows, knees, shoulders, and hips are the most important in defining the action for the observer suggesting that the perceptual stimulus of the point-light display decreases near the extremities.

Accurate perception of biological motion is highly vulnerable to inversion and although historically the majority of spatial manipulations performed show some decrements in accuracy, dramatic recognition errors have been revealed with inversion (e.g. Sumi, 1984). While the

previous emphasis of biological motion has utilized point-light display, because of the similarities it is also important to acknowledge the contribution of inverted static facial recognition (Rossion, 2008; Valentine, 1988; Yin 1969). In general, recognition performance decreases with an increase in the angle between the actor and the observer and it has been argued by Troje (2003) that this dependence functions locally and not from an environmental perspective. Lobmaier and Mast (2007) suggest however that this is not exclusively the case and the observer's orientation with respect to the environment, i.e. gravity, significantly impacts the results independent of the phase between the action and the observer. Knowing the spatial orientation of the figure beforehand does not help in accurate recognition of the action (Pavlova & Sokolov, 2000). This result led the authors to suggest that humans cannot mentally rotate biological figures. However a wealth of information exists in contradiction. Even with minimal practice people can accurately determine the action of inverted biological motion (Hiris et al., 2005; Shiffrar & Pinto, 2002). Independent of human faces, expertise has been shown using trained dog show judges to be paramount in the accurate recognition of specific biological parameters during inverted observations (Diamond & Carey, 1986). Nevertheless, image cues specific to human faces tend to produce fewer inversion errors than with other complex objects such as landscapes or inanimate objects (Yin, 1969). This has been exemplified with a category of face manipulations known as "Thatcherized" faces where the eyes and the mouth of a face are inverted (Thompson, 1980). During right-side up perception a grotesque quality is immediately apparent but during inverted conditions significantly more time is needed to distinguish between a Thatcherized face and a normal face. Lewis (2001) showed a nearly monotonic increase in the response time for recognizing Thatcherized faces when the deviation of the angle in the picture plane of the face increased with respect to the observer. Based in part from the work of

Thompson, a host of authors have suggested that discrepancies in inverted face recognition are chiefly due to deficits in the processing of configural information (Carey & Diamond, 1977; Freire, Lee, & Symons, 2000; Leder & Bruce, 2000). The term configural information has an expansive definition and Diamond and Carey (1986) define it as Second-order relational information where the particular relative spatial characteristics of one feature to another are important and not just the feature alone. An example of this is not that the face has a nose, two eyes, and a mouth (First-order relations) but the relative location of the nose with respect to the eyes and the mouth. The global thought is that configural processing is a “holistic” approach verses a piecemeal approach (Leder & Bruce, 2000). At an extreme perspective the face is not decomposed into local features but the face is recognized as a whole where relative parameters of features are not explicitly symbolized (Farah, Tanaka, & Drain, 1995; Tanaka & Farah, 1993).

Because of the apparent recognition deficits during inverted perception of biological motion (Sumi, 1984), there is a debate as to the prevalence of low-level visual mechanisms compared to higher order, conceptually driven mechanisms in human motion perception. The primary distinctions between top-down and bottom-up visual processing is the time required for the process to occur, usually considered the time interval between stimuli, and the level of attention required to perceive the specific cues. Johansson’s initial work on vector analysis modeling (Johansson, 1979) using point-light display suggested that low-level, bottom-up processing dominates the visual perceptual process. He argued that the vectors defined from the point-light markers moving across the retina establish a single structure percept of the action suggestive of a process void of any higher order mechanisms. Working on the assumption that low-level processing is limited to brief time periods, the work of Webb and Aggarwal (1982) and Mather et al. (1992) propose that motion perception is bound to the same constraints and are

indicative of bottom-up visual processing. Webb and Aggarwal developed a method for recovering three-dimensional motion from several two-dimensional viewpoints where the output of the theory is similar to Johansson's and a single percept is developed. Hoffman and Flinchbaugh (1982) developed a related theory for human motion perception where a fundamental assumption about the nature of the object being observed facilitates the percept. Their work was in part influenced by Ullman (1979) who suggested that motion perception was a bottom-up process assisted by direct perceptual information influenced by basic assumptions about the object being observed. In recent years, however, the focus has shifted to a more cognitively rich, top-down visual process for human motion perception where equivocal support has been formed. Using the assumption that low-level processing relies on a short time interval between stimuli, Thornton, Pinto and Shiffrar (1998) found that people can accurately perceive point-light walkers even when the time between stimuli was 120 ms greatly exceeding normal time intervals associated with bottom-up processing. Thornton et al. (2002) also showed deficits in direction perception of point-light walkers during a dual-task paradigm when the observers attention was divided. Both studies suggest that perception of point-light display is at least in part dependent on higher order, cognitive processing. Using an array of extra markers as noise, Cavanagh et al. (2001) showed that the time increased in determining an "oddball" point-light walker implying that the burden in attentional resources made the task more cognitively demanding. Even the motion of the point-light walker independent of other spatial cues provides a frame of reference to establish the logic of the moving markers where the implication is that potential low-level perceptual components are influenced suggesting a process dominated by higher-order processes (Tadin, Lappin, Blake, & Grossman, 2002).

## Mental Rotation

The ability to perceive inverted human motion originates with the ability in humans to mentally manipulate an object in three-dimensional space. The first sincere notion of mental rotation was born out of the work of Shepard and Metzler (1971) where during a recognition task of two differently oriented three-dimensional objects, participants reported using a mental rotation strategy to manipulate the image of one object to the orientation of the other. The paired objects were systematically rotated in both the picture plane and the depth plane and the response times were recorded. Rotations in both the picture plane and the depth plane showed linear, monotonic increases in response times as a function of the deviation angle between the objects. In an attempt to understand the mechanism that made such a task possible, Shepard and Metzler tentatively suggested that humans can perform elaborate three-dimensional imaginary rotations of objects where the time required to perform such a rotation is a function of the amount of rotation required. Using spatial and recognition priming as a tool Cooper and Shepard (1973) found that the amount of time the participant was aware of the stimulus angle prior to testing directly affected the amount of time required to perform the recognition task. They proposed that when given sufficient time (~1s) people can perform the mental rotation *a priori* and in turn complete the recognition task in the same amount of time as in the non-rotated condition. Both studies provided seminal foundations for a line of research focused around human being's ability to manipulate the spatial orientation of an object mentally.

Over the years an array of manipulations have been made on the original Shepard-Metzler shapes fondly named for Shepard and Metzler (1971) where discrepancies in mental rotation abilities have been shown between different ages, sexes, and even the blind. Although it may seem a subtle point, in the original work of Shepard and Metzler (1971), Cooper and

Shepard (1973), or even Shepard and Cooper (1982) there is no explicit mention of whether or not the mental strategy used to represent the object is visual. Substantial research exists to support the claim that visually impaired individuals use an alternative, non-visual, imagery technique to perform mental rotation tasks (Cattaneo, 2008). In a majority of the mental rotation tasks where the stimulus can be presented tactilely, visual impaired people, even congenitally, can perform equally well as sighted individuals (e.g. Marmor & Zaback, 1976). Sex differences in mental rotation abilities have been implied since the line of research's inception. A number of early studies suggested a significant male advantage (Harris, 1978; Maccoby & Jacklin, 1974; McGee 1979; Resnick, 1993), while others have shown small or even insignificant differences (Caplan, Macpherson, & Tobin, 1985; Hyde, 1981; Sherman, 1978). More recent work has attempted to draw parallels between the female menstrual cycle and mental rotation abilities (Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Gunturkun, 2000). The data suggests that hormone levels are partly responsible in the time required for a person to match two three-dimensional objects that are in different spatial orientations. As with the proposed sex differences in mental rotation abilities, there exists confounding data as to human's mental rotation abilities across the lifespan. Gaylord and Marsh (1975) found an 84% increase in the time required for elderly individuals to perform a mental rotation task when compared with college students. However using a different set of stimuli, Jacewicz and Hartley (1979) showed no age differences. Although subsequent studies have shown dramatic difference with elderly populations (Berg, Hertzog, & Hunt, 1982; Cerella, Poon, & Fozard, 1981), Childs and Polich (1979) showed differences during the earlier stages of development only when advanced information about the stimulus was provided. Between 9, 11, and 20 year old participants, the only difference reported was that the response times for the oldest group remained constant when

they were given advanced knowledge about the orientation of the stimulus. This was not found in the other two age groups where advanced knowledge did not impact the results.

Another area left untouched by the early work in this field in understanding the type of mental rotation being performed where two primary strategies exist; an egocentric or retinal rotation and an allocentric or global rotation. An egocentric rotation is classically defined as rotating the object within the local coordinate system of the observer. An allocentric rotation is where the observer mentally rotates the object within the global coordinate system which may or may not be the same as the observer's coordinate system. The importance of reference frames is succinctly outlined by Robertson, Palmer, and Gomez (1987):

The frame hypothesis suggests that mental rotation tasks are accomplished in the following way. First, it must be assumed that the subject has an "internal" reference frame (RF) that defines the current sense of direction relative to a subjective upward direction. Normally, this internal RF will in fact be aligned with other perceptually salient RFs such as gravitational upward and the sagittal plane of the eye, head, and body. Under certain circumstances, however, people seem to be able to transform this internal RF so that it aligns with intrinsic structural characteristics of a misoriented stimulus. (p. 368).

Indeed, the following is an even more lifelike example from Koriat and Norman (1984):

Assume that you find a newspaper on your desk, but the main headline (top) is nearest to you, that is, the print is upside down. If you want to read that paper you will probably choose between two courses of action: either to flip the paper 180° or to walk to the opposite side of the desk. (p. 421).

Early work suggests that the particular strategy employed may depend on the observer's interpretation of which reference frame the object should exist in (Corballis, Zbrodoff, &

Roland, 1976) although the gravitational reference frame may exert a stronger influence (Corballis, Nagourney, Shetzer, & Stefanatos, 1978). This has been reinforced with the work of Shepard and Hurwitz (1984) who proposed that human's dependence on gravity in spatial mapping extends far beyond basic mental rotation tasks and provides a frame of reference for defining planer map directions. In a series of experiments to understand the response time dependence originally displayed by Shepard and Metzler (1971), Koriat and Norman (1984) showed a greater response time dependence on spatial deviations from the vertical when compared to deviations from previous trials. The authors imply that for basic shape matching the data supports the use of only the image rotation hypothesis and not the mental rotation of the observer's frame of reference. Koriat and Norman did not actually change the orientation of the observers and solely relied on the change in picture orientation from trial to trial. Using the "Thatcherized" faces previously mentioned, Lobmaier and Mast (2007) systematically rotated the observer and the images to process a series of in phase and out of phase combinations in the picture plane. The researchers showed that the angle of deviation between the observer and the image is primarily responsible for the accuracy and the response time of the observer. However when the observer was at 135° of rotation, decrements in accuracy and response time were greater than what would have been expected. These data suggests that although primarily confirming the work of Koriat and Norman, the phase angle between the stimulus and the observer is not the only significant element. Because of human being's understanding of and relationship with gravity, the defined environmental reference frame is dominated by the proprioceptive, vestibular, and visual systems by which up is generally defined as in the opposite direction to the gravitation force. In space travel or parabolic flight investigations, where gravity is no longer present, the supposition is that humans rely on any available proprioceptive

information to define a global coordinate system with which to mentally rotate objects (Gurfinkle, Lestienne, Levik, Popov, & Lefort, 1993; McIntyre, Lipshits, Zaoui, Berthoz, & Garfinkel, 2001).

The clear dominance for using an egocentric reference frame when mentally rotating objects may primarily be a function of the type of object and the use of a human figure as the “embodied” stimulus for mental rotation studies can produce very different results (Amorin, Isablue, & Jarraya, 2006). In an attempt to understand the role of the human form in mental rotation tasks, Sayeki (1981) showed different groups of observers both classic Shepard-Metzler shapes and Shepard-Metzler shapes with a three-dimensional figure of a human head attached. The idea was to provide a body analogy to what would otherwise be an arbitrary object. Sayeki found that people are much better at mental rotation matching tasks when the human form is introduced. The human analogy was not explicitly stated to the observers indicating that people have rich resources for dealing with the spatial orientation of the human form. Using the body as a metaphor is typical in both physical descriptions and in abstract terms (e.g., “I am looking *forward* to the party tomorrow” or “The chair is *behind* the desk”), and its influence on humans spatial understanding is profound (Amorin et al., 2006). When objects have a clear body mapping the reference frame used is implicit yet when the body mapping of an object is void the reference frame of the object is dependent on the observer (Lakoff & Johnson, 1999). A bicycle or automobile has a clear front and back because it has an implicit map, independent of the environment, based on the reference frame projected from a potential user interacting with the object. This map becomes less clear when presented with an object that does not have a specific spatial affordance such as a coat rack. In this case the front of the object is dependent on the environment and what portion the observer can actually see. This distinction becomes less clear

when considering an object such as a television where the majority of people would define the front as the screen and the back as the area where the connections are. In this case the body projection is ambiguous because the mapping is independent of the environment but does not match the frame of reference of the person interacting with the television either. In other words, people do not interact with the television by sitting beside it oriented with their front in the same direction as the television screen.

One of the seminal works in understanding the role of the body as a metaphor for spatial manipulations was once again established by Shepard in a spatial recognition task of the left or the right hand where participants were presented with line drawings of either the back or the front of a hand (Cooper & Shepard, 1975). They proposed the following:

Subjects determine whether a visually presented hand is left or right by moving a mental "phantom" of one of their own hands into the portrayed position and by then comparing its imagined appearance against the appearance of the externally presented hand. (p. 48).

This work was expanded on by Parsons with a comprehensive series of studies (Parsons, 1987a, 1987b). Parsons not only examined spatial orientation in the identification of left and right with human figures, but he also examined the influence of body postures rotated to different static positions in the three cardinal axes and in a variety of oblique combination axes. His study further emphasizes the influence of the specific object on the type of mental rotation performed and intern the reference frame used. These data suggests that the most convenient mental representation of a body part for comparing with an external stimulus is actually the observer's own body part. In other words, the best way to determine if the image of a hand in three-dimensional space is either the left or the right hand is to imagine one's own hand moving to that orientation. This is a novel thought when compared to previous work suggesting that people are

generally not capable of imagining a spatial rotation of their own perspective (Cooper & Shepard, 1973; Hintzman, O'Dell, & Arndt, 1981; Huttenlocher & Presson, 1973; Koriat & Norman, 1984; Presson, 1982).

Both Cooper and Shepard (1975) and Parsons (1987b) suggested that the anatomical nature of the object itself helps define the rotation strategy employed. In an attempt to understand what role typical anatomical constraints may play in the mental rotation strategies, Petit and Harris (2005) used both possible and impossible human actions as the stimulus for a mental rotation task. In the first of two experiments observers were presented with spatially transformed pairs of either possible or impossible human body postures. The response times increased in the comparing of impossible postures. In the second portion observers had to determine whether or not a spatially transformed figure was in a possible or impossible posture. Under this condition typical mental rotation functions only occurred with possible postures. The data suggests that the familiarity to the object is paramount and when possible postures were presented individuals employed an embodied rotation and when impossible postures were presented individuals used a classic Shepard-Metzler shape, egocentric mental rotation strategy. In general the thought is that embodied rotations are faster due to the familiarity of one's own body when compared to an arbitrary object or an impossible human shape. These findings do not suggest however, that rotation strategies used in embodied transformations do not still rely on gravity. On the contrary the embodied rotation being performed is occurring in a global coordinate system and not the local coordinate system of the person. Indeed the person's local coordinate system is being transformed to a more favorable orientation with respect to the environmental reference frame. In an attempt to understand the role of gravity in defining this global coordinate system during embodied mental rotations Grabherr, Karmali, Bach, Indermaur, Metzler, and Mast (2007)

investigated embodied mental rotations in the absence of gravity. The task was similar to that of Cooper and Shepard's (1975) hand recognition task and the researchers showed that both response time and error rates increased in microgravity conditions. Because the task requires an embodied rotation with a sound environmental orientation as the frame of reference, in the condition where gravity was not present the environmental frame of reference was harder to establish and provide a reliable origin to complete the embodied rotation (Grabherr et al., 2007). A number of other studies showed contrasting findings where no differences were obtained between the normal gravity and the microgravity conditions when using Shepard-Metzler shapes or other non-humanoid geometries (Leone, 1998; Leone, Lipshits, Garfinkel & Berthoz, 1995a, 1995b). Combined, the microgravity studies confirm the idea that the familiarity to the observed object helps define the type of rotation performed and when a reliable environmental frame of reference is not possible, the potentially preferred embodied rotation is more demanding.

### Research Problem

The present experiments were an attempt to understand the mental rotation strategies that are employed in determining the rotation direction of the human form. Of specific interest was the influence of body orientation and observer experience. Although there has been extensive research on point-light and inverted point-light perception of biological motion (e.g., Hiris, Krebeck, Edmonds, & Stout, 2005; Shiffrar & Pinto, 2002b; Sumi, 1984), there is rarely a mention of the reference frame used or whether or not the observer performed an embodied transformation to accurately identify the action. Because of the wealth of relative joint kinematic information present (Kozlowski & Cutting, 1977; Cutting, Proffitt, & Kozlowski, 1978), a basic transformation may not be possible as in the hand or arm identification studies of Parsons

(1987a), Cooper and Shepard (1973), and Grabherr et al. (2007) where the distinction may lie in the absence of motion. The idea of embodied spatial transformations has yet to be applied to biological motion. It is unclear whether the observer performs a mental rotation in point-light display tasks because the relative joint information is too robust to limit the success or failure to a particular strategy. It may be the case that particular markers or body parts are spatially transformed but the number of moving dots on the screen makes it difficult to determine. One of the basic assumptions of embodied rotations is the ability to project human parameters such as front, back, right, and left onto the object or figure being observed (Parsons, 1987a, 1987b). With classic biological motion perception tasks this opportunity never arises because the recognition of the action precedes the metaphorical body mapping onto the actor being viewed.

The major point of contention in the fundamental theories of visual perception is the role of knowledge of the environment and the action in guiding the veridical perception. Although researchers have shown improvements in the perception of point-light display with training (Hiris, Humphrey, & Stout, 2005; Shiffrar & Pinto, 2002), it is unclear how and in what way this information is used to increase the accuracy of the recognition. Early inferential perception theorists (Duncker, 1929; Asch & Witkin, 1948) employed the use of reference frames and Rock (1973) suggests that the very use of a reference frames provides a distinction that an inferential approach is used in perception. This is only the case when a global reference frame is used but may not be true if all of the manipulations are being performed at the retinal level. A basic conjecture of Gibson and Carmichael (1950) is that visual perception is completely mediated by bottom-up processes. Being able to select the best or even the most probable interpretation relies on past experiences and knowledge of the environment for the appropriate selection. Even direct perception theorists suggest that action within the environment is critical for understanding the

texture gradients stimulating the retina. As a result, an aspect of the investigation was to understand the role of both perception and action expertise or experience in the spatially manipulated perception of biological motion.

At present, studies related to the perception of biological movement have focused on either a specific movement or a specific static posture with little effort at understanding the perceptual relationship between the two. The primary goal was to understand the extent that humans are capable of accurately perceiving both their own rotations and the rotations of others and how do spatial manipulations of the actor and the perceiver affect the perception of the action. Rotation is a common human movement typically accompanied by additional kinematic cues. In specific sports, however, there are instances where a human may be rotating in the air and the relative kinematics between body segments is unchanged, thus being both internally static and externally dynamic. This occurs regularly during twisting skills in the sports of figure skating, diving, gymnastics, snowboarding, and aerial ski jumping.

Experiment 1 was designed to provide a basic framework of understanding how humans perceive another rotating human form. Because the specific stimulus of observing a rotating human body has rarely been utilized it is important to use the primary experiment to, in part, provide a perceptual ability baseline for subsequent examinations. To understand the role of expertise in the perception of human rotation both expert rotators and novices were examined. The initial experiment examined both participant judgment response time and judgment accuracy in determining the twisting direction of another human. The participants were asked to report the twisting direction of the human form from the human form's perspective with a verbal "right" or "left" response. This examination was conducted using individuals that were novices or experts at rotating in the air by using non-athletes and expert level gymnasts. Although a variety of

sports afford twisting activities, gymnastics provided the appropriate recipe of multiple twists in a variety of spatial orientations where, for at least a portion of the skill, the gymnast remains internally static. To investigate the role of gravity and the external reference frame on the perceptual metrics of the observer, the human form was shown in a variety of static spatial orientations. Participants observed a human form rotating about the longitudinal axis while being statically oriented in a series of rotated picture plane orientations throughout the entire 360°. It was hypothesized that participants would not be perfect when the human form was rotating upright and that the participants would require more time to respond and would be less accurate when the human form was inverted. Furthermore, both response time and response accuracy would be uninfluenced by expertise.

An inherent concern in Experiment 1 was the use of language as a tool for responding to a visual cue. Word storage and production is a complicated process sensitive to a number of issues and although participants were screened for their ability to verbally report right from left it is important to compartmentalize the use of language from the perceptual abilities of the proposed participant groups. Experiment 2 was a reproduction of the first using only novices and requiring a non-verbal action to distinguish the twisting direction of the human form. A keyboard response is common and appropriate for this study and minimizes complications associated with language. However, a keyboard response highlights an inherent concern of what button combination to use without confounding the issue. Experiment 2 investigated congruent and incongruent button combinations and, because the static spatial orientations of the human form encompasses an entire 360°, it was more appropriate to use not only buttons representing left and right but buttons representing up and down as well. Imagine a television remote control with four buttons, up, down, right, and left where up and down control the volume and right and left

control the channel selection. It is not always clear whether or not the right button will change channel 6 to 7 or channel 6 to 5. Using all four directional buttons, the interaction between a verbal and a spatial response can be examined as well as understanding the interaction between the spatial orientations of the response buttons with reference to the human form being observed. Similar to Experiment 1 participants were asked to observe a series of animations of a human figure rotating about the longitudinal axis and their accuracy at determine the correct twisting direction and response time were recorded. Four different response patterns were developed where a right button push corresponds to a right twist, the opposite where a left button push corresponds to a right twist and the vertical pair where an up or down button push could correspond to a right twist.

The underlying goal was to understand to what extent does the act of responding and the nature in which it was done effect the response of the perceived twisting action. Specifically the aim was primarily to understand what orientations and directions are easier for humans to translate from perception to response and secondarily to give legitimacy to the verbal response technique proposed in Experiment 1. In the most congruent pattern of right button equals right twist and left button equals left twist, it was proposed that the novice participants would perform similar to the participants providing verbal reports of left and right in Experiment 1 where it was expected that accuracy would decrease and response time increase as the observed action deviates further from the upright. As the button combinations become less congruent the dependency on upright would dilute. The general idea was that because the task was fundamentally challenging, humans would rely on the easiest and potentially quickest solution, which may or may not be the most accurate. It was believed that during the more cognitively demanding scenarios, such as an up and down button pair with a horizontally oriented rotating

figure, humans would use a global reference frame to draw conclusions. In the previous example it was hypothesized that the participants would press the up button if the human figure rotates up first (chest facing up) or press the down button if the human figure rotates down first (chest facing down) in spite of the actual instructions to report the correct twisting direction left or right with either an appropriate up button or down button.

While Experiment 1 and 2 were an examination of the perception of a rotating human form under manipulations of spatial orientation, the same perceptual task was examined where the observer was spatially manipulated as well. The spatial orientation of both the observer and the actor investigated in concert would provide a more holistic interpretation of the influence and the category of reference frame used during the perceptual task. Without rotating the observer there was no way to determine if the hypothesized decrease in accuracy during the inverted stimulus conditions was a function of the angle discrepancy between the observer and the participant, the orientation of either the observer or the rotating human form, or both. An apparatus was used to rotate the participant to a static position in the picture plane in conjunction with the static orientation of the observed rotating figure. To accurately tease this apart all possible combinations of static orientations for both the participant and the figure being observed were examined. It was proposed that both the absolute spatial orientation of the participant and the spatial relationship of the participant to the observed human form would affect the perceptual accuracy. It was hypothesized that observer orientation would have a minimal impact on the perceptual accuracy or response time of the observer. Humans spend very little time in an inverted state and as such it was proposed that a vertical representation of the world would still be used to make a judgment regardless of the actual orientation of the observer. In other words it was proposed that perceptual accuracy would decrease as the avatar approaches 180° of rotation

with respect to the world and not with respect to phase angle between the observer and the avatar. Each of the experiments focused on the perceptual abilities of a participant observing another human form rotating and the compliment was to examine participants perceiving their own rotational direction. Instead of observing an external human form, participants were actually rotated either right or left and asked to report which direction they were turning. Essentially it was a mirror of Experiment 1 except the observer and the actor were one in the same. With Experiment 4 the potential existed to draw a more detailed picture as to the relationship between the doer and the seer with respect to the perception of human rotation. As such both experts and novices were again used. The participants were physically rotated about the vertical axis while they were held in a variety of picture plane orientations. In contrast to Experiment 1 it was hypothesized that a stark distinction would exist between the expert doers and the novices. Indeed novice participants would have a much harder time articulating which direction they are rotating when they are inverted. Combined with Experiment 1, it was hypothesized that the simple act of watching a human form rotate would provide a scenario in which both the observer and the actor were in agreement and have both perceived the incorrect direction. Indeed, when the avatar is right-side up the observer would accurately determine the correct twisting direction of the avatar. As the avatar approached inversion accuracy would decrease. This would also be true when the participant was actually rotated where the novices would be able to accurately determine their own twisting when they were right-side up but their accuracy would decrease as they approached an inverted state.

## EXPERIMENT 1

### Introduction

The detrimental effect of inversion on the accuracy of face recognition and the perception of biological motion has been studied for over 40 years (Brooks & Goldstein, 1963; Johansson, 1973). It has been argued that face recognition, as compared to the recognition of other objects, is a specific perceptual and encoding process that is particularly sensitive to stimulus orientation (Yin, 1969a). This specific process has been credited both for and against interference in configural processing specific to faces during inverted conditions (Diamond & Carey, 1986; Freire et al., 2000; Leder & Bruce, 2000; Rossion, 2008) where configural processing is the recognition of spatial variations between features and not necessarily the recognition of individual variations within each physical feature.

In the study of biological motion the majority of the studies related to orientation dependency use point-light displays and focus on the dynamic relationship of joint locations (Johansson, 1973; Kozlowski & Cutting, 1977). Little work has been done on the perceptual accuracy of intact biological motion in a variety of spatial orientations (cf. Barclay et al., 1978) and to date no one has studied the orientation dependency on the perception of biological motion where the human form is dynamic yet no changes in configural information occur.

Accurate judgments about inverted rotated objects are improved by either imagining the rotation of one's body (egocentric) or by imagining the rotation of the object (allocentric) to a more favorable position (Parsons, 1987a). Increased cognitive demands are apparent with greater angular discrepancies between the individual and the world they are perceiving (Shepard &

Metzler, 1971). Researchers have historically attributed the increased cognitive demands to either an egocentric or allocentric mental rotation strategy, but rarely both.

The notion of a strategy implies a developed or methodical approach. However, it has been argued extensively by Gibson and Carmichael (1950, 1966) and Gibson (1979) that higher brain functions are minimal during visual perception and the environment is exclusively responsible for what the individual may perceive. This theory relies on a synergy between perception and action where the visual perception pathway goes directly from retina to motor response without inferential input. A raft of research however has suggested the contrary where inference is a critical component in visual perception tasks (Helmholtz, 1867; Koffka, 1935; Köhler & Wallach, 1944; Marr, 1982; Palmer, 1997; Rock, 1977, 1983; Rock & Ziegler, 1997). The nature in which the inferences are developed has been debated. However the basic premise is that experience and expertise is paramount in visually observing the veridical. Therefore the present experiment investigates the role of experience in the spatial perception of another human form. Indeed, the fundamental query is focused around the experiential relationship between perception and action; is the expert mover better at perceiving the veridical when compared to the naïve participant? The conjecture is that the increased cognitive demands of inverted, dynamic spatial perception are so dramatic that the contribution due to the individual's expertise in action will be moot.

## Methods

### *Participants*

Twenty participants were recruited from the University of Illinois community and were comprised of faculty, staff, and students. Participants had no known visual, cognitive, or vestibular impairments. The participants consisted of two groups; 10 novices and 10 experts. The novices were defined as having never participated in the sports of figure skating, diving, gymnastics, snowboarding, and aerial ski jumping. The experts were all members of the University of Illinois men's and women's division I gymnastics team. All participants were screened to determine that they could distinguish left from right by asking them to complete a series of rotations of either left or right from their perspective while standing in place in a pre-testing area. Participants that turned the wrong direction were excluded from the study. The expert and novice groups were gender matched.

### *Apparatus*

The participants observed an animated figure on a Dell TFT 19 inch monitor (model E197FP) located 18 inches away from the observers face and perpendicular to their gaze. The participants head position was stabilized by resting their chin on an adjustable height platform (3rd Hand by Duluth Trading Company). The avatar was a three dimensional rendering of a clothed, male human form generated by Bryce 5.0. The avatar was 220 pixels wide and 700 pixels tall and was displayed on the monitor with the resolution set to 1024 x 768 (see Figure 2). The video display, recording of audio response and calculation of verbal response time was all done using a GUI program written in MATLAB (version R2009a). The verbal response time

was calculated by a minimal auditory threshold response based on the volume units (VU) of the sound being recorded by a microphone directly in front of the participant's mouth (Sennheiser model MKE400).

### *Procedures*

Participants from each group were asked to observe a series of animations on a computer monitor of a human figure, or avatar, rotating about the longitudinal axis. The participants were asked to report as fast and accurately as possible the twisting direction of the avatar from the avatar's perspective with a verbal "left" or "right" response. The avatar was randomly displayed in one of 6 static increments of 60 degrees of rotation about the anterior-posterior axis (picture plane angles of 0 degrees, 60 degrees, 120 degrees, 180 degrees, 240 degrees and 300 degrees). Each of the left twisting and right twisting animations for all of the 6 picture plane angles were randomly assigned such that the participant viewed all 12 animations (6 angles by 2 directions) in a random order before the next set of 12 randomized animations were displayed. The participant observed the entire set of 12 animations for 10 trials. The avatar completed three revolutions at a rate of 1 Hz. Verbal response of either "left" or "right" and response time were recorded. Response time was defined as the time interval from onset of visual stimuli to the beginning of the participant's verbal response. The participant's response of "left" or "right" was entered into the computer program by the experimenter before the next visual stimuli was displayed. The experimenter could not see the visual stimuli and only recorded the response provided by the participant. All participants were given initial practice trials to ensure the instructions of determining the twisting direction from the avatar's perspective was understood.

### *Data Analysis*

The data were compiled using MATLAB (version R2009a) and all statistical analyses were done using SPSS (version 16.0). All figures were generated using Excel (version 2007). Accuracy was determined post-hoc and defined as either 1 for a correct response (i.e. the participant reported “right” and the avatar was turning right) or 0 for an incorrect response. Response time and accuracy were analyzed using a repeated measures analysis of variance (ANOVA). The static avatar orientation (0°, 60°, 120°, 180°, 240°, 300° in the picture plane) was the within-subject variable and gender and expertise were between-subject factors. Modifications to the degrees of freedom were reported as either Greenhouse-Geisser correction or Huynh-Feldt correction. The Greenhouse-Geisser correction was reported when the Huynh-Feldt epsilon was less than 0.75 (cf. Ionta et al., 2007). Post-hoc analyses were done using Bonferroni corrected main effects.

### Results

Mean accuracy and response time for both experts and novices at each of the six static picture plane orientations are illustrated in Figure 3. A repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on mean accuracy ( $F(2.692, 43.079) = 22.145, p < 0.001, \eta_p^2 = 0.58$ ). Post hoc test using Bonferroni correction revealed that the mean accuracy at the inverted avatar angle (180 degrees of rotation) was significantly different from all other avatar angles ( $p \leq 0.001$  for all angles). There was no significant difference in mean accuracy for the between subject measure of expertise ( $F(1,16) = 0.707, p = 0.413, \eta_p^2 = 0.042$ ) where accuracy at all angles was almost identical. A repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar

picture plane orientation on the mean response time ( $F(2.084, 33.350) = 17.778, p < 0.001, \eta_p^2 = 0.53$ ). Post hoc test using Bonferroni correction revealed that the mean response time at the inverted avatar angle (180 degrees of rotation) was significantly different from all other avatar angles ( $p \leq 0.01$  for all angles). Although the mean response time of the experts was systematically slower at all avatar orientations, there was no significant difference in mean response time for the between subject measure of expertise ( $F(1,16) = 1.723, p = 0.208, \eta_p^2 = 0.097$ ). There was no significant difference between males and females for either mean accuracy ( $F(1,16) = 0.932, p = 0.349, \eta_p^2 = 0.055$ ) or mean response time ( $F(1,16) = 0.980, p = 0.337, \eta_p^2 = 0.058$ ).

### Discussion

The accurate perception of human movement even at its simplest form is both challenging and cognitively demanding. Both expert level gymnasts and novices showed non-perfect and relatively slow judgments even in the condition where the avatar was upright. In the inverted conditions both experts and novices revealed even slower responses with judgments at nearly 50% accuracy. Examination of individual participants revealed that 3 of the 20 participants were 75% accurate or better on each picture plane angle and 3 of the 20 participants were worse than chance on each of the picture plane angles. The remaining 14 participants showed results very similar to the averaged data suggesting that not only is the task of accurately determining the correct twisting direction of an animated figure inherently challenging when right side up, it is so profoundly more challenging during the inverted condition that participants were left with no other alternative than to basically guess. It is unclear why some individuals are better or worse at the task. However it is worth noting that the 3 participants that performed extremely poorly were

all from the novice group but the 3 participants that performed extremely well were not all from the expert group. Furthermore neither small group was comprised exclusively of males or females. Although the effect of expertise on the mean response times was not significant, the experts showed in many cases to be slower at judging than the novices. When asked many of the experts reported that they thought they should be good at this task because of their gymnastics expertise and therefore used the entire length of the stimulus (3000 ms) to calculate a response. It is apparent however that the extra time made no difference in their accuracy of judgment.

## EXPERIMENT 2

### Introduction

It has been argued by Shepard (1981) that some of the most influential human constraints are so inherent that they blur the very circumstances in which humans perceive the world. In the translation of dimensional planes, humans utilize an internally consistent naming structure to bridge one direction and directional name with another (Shepard & Hurwitz, 1984). This type of language, at least in English, is common; “Let’s go down to the store” or “Please come up to the front of the bus.” Moreover Shepard and Hurwitz (1984) argued a robust relationship between the three-dimensional world and the two-dimensional surface on a map building an affiliation between the word “up” and the compass heading of north on a map.

Other directional associations have been suggested and Sayeki (1981) used the analogy of the directional light switch on a moped to outline a rationale for adding human characteristics to the classic Shepard-Metzler shapes (Shepard & Metzler, 1971). The idea was that the switch on to moped handlebars was mounted vertically and had three positions; off in the middle, up for the left directional, and down for the right directional. This type of configuration is common and without any apparent consensus where an up/down alignment controls a right/left device, or the inverse where a right/left alignment controls an up/down device. This is noticeable with almost all four-burner kitchen ranges where all four burner controls are in a horizontal alignment but control the burners in four different quadrants on an orthogonal plane. There appears to be no convention as to which knob controls which burner and it also seems apparent that particular combinations seem to be more or less congruent than others. This is demonstrated in the literature as equivocal data suggesting that both right/up and left/up associations are dependent

on the nature of the stimulus and the orientation of the response (Adam, Boon, Paas, & Umiltà, 1998; Bauer & Miller, 1982; Nicholls, Loftus, & Gevers, 1998; Proctor & Cho, 2006).

A number of studies have focused on hand preference and position and Bauer and Miller (1982) suggest that a right/up association is appropriate for right handed responses and a left/up association is appropriate for left hand responses. While Bauer and Miller (1982) argued for difference in hand preference, the work of Weeks and Proctor (1990) suggests that the stimulus-response compatibility is independent of hand preference. The majority of work on spatial stimulus-response compatibility has focused on a discrete set of orthogonal stimulus and response patterns with little mention of understanding the spatial relationship across two entire orthogonal planes. Furthermore little work has been done in understanding stimulus-response compatibility with a spatially dynamic stimulus.

Weeks and Proctor (1990) support the classical notion that orthogonal stimulus and response patterns are the effect of a translational mechanism independent of whether the response is verbal, unimanual, or bimanual. In contrast, Umiltà (1991) suggests an alternative interpretation based on the notion that orthogonal stimulus-response sets do not yield natural links and therefore may need to rely on both a vocal and a manual translational component. To reconcile these contrasting ideas, the present study is an attempt to provide a similar unimanual stimulus-response paradigm except where a natural pairing between orthogonal planes does exist. The translation mechanism hypothesis relies on salient and non-salient spatial orientations and the goal in this study is to introduce a dynamic stimulus that not only provides a natural link between the orthogonal planes but removes the notion of salient and non-salient orientations.

## Methods

### *Participants*

Participants were recruited from the University of Illinois community comprised of faculty, staff, and students. Participants had no known visual, cognitive, or vestibular impairments. The participants were all novices in the field of rotational perception or action and were defined as having never participated in the sports of figure skating, diving, gymnastics, snowboarding, or aerial ski jumping. All participants were screened to determine that they could distinguish left from right by asking them to complete a series of rotations of either left or right from their perspective while standing in place in a pre-testing area. Only participants that reported right hand dominance when writing were used for the experiment. Participants that turned the wrong direction were excluded from the study. Eighty participants were used, 40 males and 40 females.

### *Apparatus*

The participants observed an animated figure on a Dell TFT 19 inch monitor (model E197FP) located 18 inches away from the observer's face and perpendicular to their gaze. The participant's head position was stabilized by resting their chin on an adjustable height platform (3rd Hand by Duluth Trading Company). The avatar was a three dimensional rendering of a clothed, male human form generated by Bryce 5.0. The avatar was 220 pixels wide and 700 pixels tall and was displayed on the monitor with the resolution set to 1024 x 768 (see Figure 2). The video display, recording of the button response and response time was all done using a GUI program written in MATLAB (version R2009a). The button response was captured using the

arrow keys on a Logitech USB keyboard (model K120). The keyboard response times were corrected for by the mean latency time of USB keyboard devices operating in windows outlined by Ramadoss (2008).

### *Procedures*

The participants were randomly divided into four gender matched groups of 20 participants. Each group of participants was asked to observe a series of animations on a computer monitor of a human figure, or avatar, rotating about the longitudinal axis. The participants were asked to report as fast and accurately as possible the twisting direction of the avatar from the avatar's perspective with an arrow button keyboard response. Each of the four groups was asked to use one of the following arrow button combinations to respond: Pattern 1, a perceived right avatar twist responded with a right arrow and a perceived left avatar twist responded with a left arrow; Pattern 2, a perceived right avatar twist responded with a left arrow and a perceived left avatar twist responded with a right arrow; Pattern 3, a perceived right avatar twist responded with an up arrow and a perceived left avatar twist responded with a down arrow; and Pattern 4, a perceived right avatar twist responded with a down arrow and a perceived left avatar twist responded with an up arrow. All participants were asked to push the arrow keys with their right index and middle fingers (see Figure 4). The avatar was randomly displayed in one of 6 static increments of 60 degrees of rotation about the anterior-posterior axis (picture plane). Each of the left twisting and right twisting animations for all of the 6 picture plane angles was randomly assigned such that the participant viewed all 12 animations in a random order before the next set of 12 randomized animations were displayed. The participants observed the entire set of 12 animations for 10 trials. The avatar completed three revolutions at a rate of 1 Hz. Both the

accuracy and the response time were recorded. All participants were given initial practice trials to ensure the instructions of determining the twisting direction from the avatar's perspective were well understood.

### *Data Analysis*

The data were compiled using MATLAB (version R2009a) and all statistical analyses were done using SPSS (version 16.0). All figures were generated using Excel (version 2007). Accuracy was determined post-hoc and defined as either 1 for a correct response (i.e. the participant reported "right" and the avatar was turning right) or 0 for an incorrect response. Response time and accuracy were analyzed by means of a mixed design analysis of variance (ANOVA). The static avatar orientations (0°, 60°, 120°, 180°, 240°, 300° in the picture plane) was the within-subject variable and gender and button pattern were the between-subject factors. Modifications to the degrees of freedom were reported as either Greenhouse-Geisser correction or Huynh-Feldt correction. The Greenhouse-Guisser correction was reported when the Huynh-Feldt epsilon was less than 0.75 (cf. Ionta et al., 2007). Post-hoc analyses were done using Bonferroni corrected main effects.

### Results

Mean accuracy and response time for all four response patterns at each of the six static picture plane orientations are illustrated in Figure 5. A repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on mean accuracy ( $F(2.340, 168.514) = 5.048, p = 0.005, \eta_p^2 = 0.066$ ). Post hoc tests using Bonferroni correction revealed that the mean accuracy at the inverted avatar angle (180° of

rotation) was significantly different from 240° of rotation ( $p = 0.014$ ). The between subject measure of button response pattern on the mean accuracy ( $F(3,72) = 2.343, p = 0.080, \eta_p^2 = 0.089$ ) approached significance. However there was a significant interaction between avatar picture plane orientation and response pattern on the mean accuracy ( $F(7.021, 168.514) = 4.083, p < 0.001, \eta_p^2 = 0.015$ ). There was no significant effect of gender ( $F(1, 72) = 0.031, p = 0.862, \eta_p^2 = 0.00$ ) however the interaction of button response pattern and gender on the mean accuracy approached significance ( $F(3, 72) = 2.662, p = 0.054, \eta_p^2 = 0.10$ ) and is displayed in Figure 6.

The repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on the mean response time ( $F(3.224, 232.132) = 40.417, p < 0.001, \eta_p^2 = 0.36$ ). Post hoc test using Bonferroni correction revealed that the mean response time at the inverted avatar angle (180° of rotation) was significantly different from all other avatar picture plane angles ( $p < 0.001$  for all angles). There was no significant difference for the between subject measure of button response pattern on mean response time ( $F(3,72) = 1.335, p = 0.270, \eta_p^2 = 0.053$ ). There was, however, a significant interaction between avatar picture plane orientation and response pattern on the mean response time ( $F(9.672, 232.132) = 2.013, p = 0.035, \eta_p^2 = 0.077$ ). There was a significant effect of gender ( $F(1, 72) = 9.018, p = 0.004, \eta_p^2 = 0.11$ ). Male's average response time (2010 ms) was shorter than female's average response time (2800 ms). The interaction between button response pattern and gender on the mean response time (Figure 6) was not significant ( $F(3, 72) = 1.430, p = 0.241, \eta_p^2 = 0.056$ ).

## Discussion

Directional mapping is unavoidable in today's world of video games, interactive websites, and smart phones where the data on a two-dimensional surface of a computer, TV, or

smart phone screen is manipulated by directional buttons or third party interactive devices. These tasks are not trivial yet people get good at it over a relatively short period of time. Most of the interactions with these devices however are void of judgment scrutiny and are rarely if ever presented in multiple spatial orientations. Indeed, when an individual is playing a first person video game they might intuitively respond to the environment by moving left or right but rarely are they asked to label the direction of travel of the stimulus that they responded to. A sport example would be a running back in football avoiding a tackle while being asked at that time to label the direction of the defenders movement. This is compounded with the introduction of spatial manipulations to the stimulus. These additional cognitive demands on the system change what would typically be choice reaction time responses to fairly inaccurate judgments that take on the order of 2500 ms to generate.

The significant effects of the interaction of avatar picture plane orientation and response pattern on the mean accuracy suggest a conflict of strategies employed by the observer. One of the strategies vying is the original approach outlined by the experiment, i.e. use the appropriate buttons that correspond to a right or left avatar rotation to accurately record the directional judgment. Although this was the outlined goal, because of the cognitive challenge it is proposed that an easier more familiar secondary strategy partly shadowed the primary; a strategy void of judgment scrutiny and more akin to typical video game responses. This strategy employed the use of an external reference frame defined by the environment and the button patterns for the task. That is, if the avatar's face rotated from the left side of the screen to right side of the screen (a left twist in the  $0^\circ$  condition and a right twist in the  $180^\circ$  condition) then the participant was compelled to choose the button corresponding to the direction of travel and in this case the right button regardless of the actual labeled twisting direction. Conversely if the avatar's face moved

from the right side of the screen to left then the participant was compelled to choose the left button regardless of actual twisting direction. The same strategy was employed with button patterns 3 and 4 using the up and down arrows. When the avatar was oriented at  $60^\circ$ ,  $120^\circ$ ,  $240^\circ$ , or  $360^\circ$  the avatar's twisting motion moved in two dimensions. At a  $60^\circ$  orientation a left twist meant the avatar's face moved from the left side of the screen to right and from the bottom of the screen to the top at the same time. Consistent with this example, participants were compelled to respond with either an up button or a right button depending on the button pattern used.

Because both strategies were in conflict it is proposed that the participants used the combination of the two when performing the task. Indeed the individual participant data sets suggest that some individuals tried to complete the original task independent of an external reference frame and relied on the original instructions and button combinations, some individuals seemed to ignore the instructions in favor of the simpler reference frame strategy previously outlined, and some individuals used both strategies throughout the trials. Figure 7 displays the mean accuracy data from Experiment 2 and what the accuracy data would look like if participants solely used the external reference frame strategy. Because the majority of the avatar angles are not exclusively upright or inverted ( $60^\circ$ ,  $120^\circ$ ,  $240^\circ$  and  $300^\circ$ ) the modeled accuracies are displayed as sine functions of the avatar picture plane angle to help account for both the vertical and horizontal influences.

The generated accuracy data outlined in Figure 7 models the actual data from Experiment 2 in two ways. The first is that the right button equals right turn pattern is inversely proportional the left button equals right turn pattern with convergences between  $0^\circ$  and  $180^\circ$  with almost 50% accuracy and the up button equals right turn pattern is inversely proportional the down button equals right turn pattern with a convergence at  $180^\circ$  with almost 50% accuracy. The second is

that the accuracy of the right button equals right turn pattern is maximal at  $180^\circ$  and a minimal at  $0^\circ$  and the accuracy of the left button equals right turn pattern is opposite. Furthermore the accuracy of the up button equals right turn pattern is maximal between  $180^\circ$  and  $360^\circ$  and minimal between  $0^\circ$  and  $180^\circ$  and the accuracy of the down button equals right turn pattern is opposite. Both points contribute to the proposed reference frame strategy.

The generated accuracy data outlined in Figure 7 also fails in two distinct ways. The first is the accuracy at  $0^\circ$  and  $360^\circ$  where although the up and down button patterns converge and the right and left button patterns diverge, the comparable accuracies are not well represented by the model where the up and down button pattern accuracies are much greater than either the left or the right button patterns. This is most likely because the up and down button patterns were not influenced by the upright avatar turning exclusively left or right and therefore the participants relied on the original experiment instructions for their judgments which could be well over 50% accuracy for just the upright condition. The second area where the model fails is with the overall attenuation of accuracies displayed in the actual data from Experiment 2. Although the model spans accuracies from 0% to 100%, the actual data is more in the range of 40% to 80%. This may be due to the fact that some of the participants averaged nearly 50% accuracy across all avatar picture plane angles.

## EXPERIMENT 3

### Introduction

The detrimental effects of inversion on the accurate perception of human faces, postures, and even non-biological stimuli have been well established (e.g., Rossion, 2008; Sumi, 1984; Valentine, 1988; Yin 1969a, 1969b). Lesser known is the effects of observing a biological stimulus in oblique angles of deviation in the picture plane other than right side-up and up-side down. Even fewer studies have appreciated a potential difference between rotating the stimuli and rotating the viewer. It was hypothesized that human's familiarity with gravity may yield different result from just rotating the stimuli when the viewer is rotated either independently or in conjunction with the stimuli.

Shortly after Margaret Thatcher became Britain's first female prime minister, Thompson (1980) proposed a unique manipulation to an image of a human face that when inverted was deceptively hard to detect. He demonstrated the manipulation with an image that the majority of people in England were familiar with at the time and he inverted just the eyes and the mouth on a portrait of Margaret Thatcher. He proposed that the manipulation was obvious during non-inverted observations but was almost undetectable when the image was observed inverted. This classic manipulation was termed a "Thatcherized face" in honor of Thompson and the Prime Minister and an eruption of studies followed. Only recently was the idea proposed to not only observe Thatcherized faces in a variety of angles within the picture plane (Lewis, 2001), but to rotate the observer as well. Lobmier and Mast (2007) used a three-dimensional rotating table to display a series of Thatcherized and non-Thatcherized faces in a variety of rotations in the picture plane for both the face image and the viewer. Rotating the viewer was insignificant

except at 135 degrees of viewer rotation where Lobmier and Mast noted that detection of the Thatcherized faces was significantly less accurate. In all other cases accuracy decreased monotonically and response times increased monotonically as the angle between the image and the viewer approached 180 degrees. An angle of significance close to 135 degrees is not unique to this study as other researchers focusing on the subjective perception of the vertical have noted detriments in accuracy at a similar angle (e.g., Kaptein & Van Gisbergen, 2004; Mast, 2000; Mittelstaedt, 1999; Schöne, 1964; Udo de Haes, 1970; Van Beuzekom & Van Gisbergen, 2000).

Even more profound detriments in accuracy and increases in reaction time during inverted perception have been noted by Contakos and Carlton (2007) in previous studies using the directional perception of human rotation. During observations of an animated human figure twisting about the longitudinal axis observers were profoundly less accurate at determining the correct left or right twisting direction during inverted conditions while producing significantly longer response times (Contakos & Carlton, 2007). The goal of the present study is to understand if rotating the observer instead of and in conjunction with the rotating stimulus yields different results than just rotating the stimulus. Furthermore oblique angles of rotation of the observer in the picture plane have been historically significant and it is noteworthy to appreciate any angles of observer rotation that yield similar results.

## Methods

### *Participants*

Participants were recruited from the University of Illinois community comprised of faculty, staff, and students. Participants had no known visual, cognitive, or vestibular

impairments. The participants were all novices in the field of rotational perception or action and were defined as having never participated in the sports of figure skating, diving, gymnastics, snowboarding, and aerial ski jumping. All participants were screened to determine that they can distinguish left from right. Because of the equipment requirements all participants were 5 foot 8 inches or shorter and weighed less than 180 pounds. Twenty participants were used, 10 male and 10 female.

### *Apparatus*

To manipulate the participant's orientation they were placed in a metal structure in a standing position that allowed for static picture plane angle placements in increments of 60°. The participant's feet were attached using snowboard bindings, their waist was secured to the apparatus using a gymnastics spotting belt and their hands were strapped to a bar above their head with hook and loop fasteners (see Figure 8).

The participants observed the an animated figure on a Dell TFT 19 inch monitor (model E197FP) located 18 inches away from the observers face and perpendicular to their gaze. The avatar was a three dimensional rendering of a clothed, male human form generated by Bryce 5.0. The avatar was 220 pixels wide and 700 pixels tall and was displayed on the monitor with the resolution set to 1024 x 768 (see Figure 2).

The video display, recording of audio response and calculation of verbal response time was all done using a GUI program written in MATLAB (version R2009a). The verbal response time was calculated by a minimal auditory threshold response based on the volume units (VU) of the sound being recorded by a wireless lavalier microphone directly in front of the participant's mouth (Nady model Dkw-1).

### *Procedures*

Each participant was placed in an apparatus that could statically hold the participant in 1 of 6 picture plane orientations from 0 to 300 degrees in increments of 60 degrees. Each participant while in the apparatus was asked to observe a series of animations on a computer monitor of a human figure, or avatar, rotating about the longitudinal axis. The participants were asked to report as fast and accurately as possible the twisting direction of the avatar from the avatar's perspective with a verbal "left" or "right" response. The participants were asked to view animations while oriented in one of the 6 picture plane observer positions. Both the observer and the avatar were randomly oriented to account for all observer and avatar static picture plane orientations and all phase angle differences. A total of 216 animations were observed to account for all combinations (3 trials by 2 twist directions by 6 avatar angles by 6 observer angles). Both the accuracy and the response time were recorded. Because of the possibility for disorientation or motion sickness participants were provided frequent breaks out of the apparatus. The room was completely dark during testing and the only thing the participants could see was the computer monitor.

### *Data Analysis*

The data were compiled using MATLAB (version R2009a) and all statistical analyses were done using SPSS (version 16.0). All figures were generated using Excel (version 2007). Accuracy was determined post-hoc and defined as either 1 for a correct response (i.e. the participant reported "right" and the avatar was turning right) or 0 for an incorrect response. The data set was compiled by taking the mean of each right and left avatar twist for all trials for every

avatar angle and observer angle to produce a 6 observer angle by 6 avatar angle matrix for both accuracy and response time.

Response time and accuracy of each averaged data set were analyzed by means of a 6 observer angles ( $0^\circ$ ,  $60^\circ$ ,  $120^\circ$ ,  $180^\circ$ ,  $240^\circ$ ,  $300^\circ$  in the picture plane) by 6 avatar angles ( $0^\circ$ ,  $60^\circ$ ,  $120^\circ$ ,  $180^\circ$ ,  $240^\circ$ ,  $300^\circ$  in the picture plane) repeated measures analysis of variance (ANOVA) with a between-subject factor of gender. Modifications to the degrees of freedom were reported as either Greenhouse-Geisser correction or Huynh-Feldt correction. The Greenhouse-Guisser correction was reported when the Huynh-Feldt epsilon was less than 0.75 (cf. Ionta et al., 2007). Post-hoc analyses were done using Bonferroni corrected main effects.

## Results

Figure 9 illustrates the mean accuracy and response time of every observer picture plane orientation for each avatar orientation relative to the observer position and not that of the world. A 6 x 6 (6 observer orientations by 3 trials by 6 avatar orientations) repeated measures ANOVA with a Greenhouse-Guisser correction revealed an almost significant main effect of avatar picture plane orientation on the mean accuracy ( $F(1.322, 37.796) = 4.267, p < 0.056, \eta_p^2 = 0.35$ ) yet no significant main effect of observer orientation on the mean accuracy was revealed ( $F(2.286, 37.796) = 1.413, p < 0.270, \eta_p^2 = 0.15$ ). No other interactions had a significant effect on mean accuracy including observer orientation by avatar orientation ( $F(4.725, 37.796) = 1.104, p < 0.373, \eta_p^2 = 0.12$ ). There was no significant difference in mean accuracy for the between subject measure of gender ( $F(1,8) = 0.112, p = 0.747, \eta_p^2 = 0.014$ ).

A 6 x 6 (6 observer orientations by 6 avatar orientations) repeated measures ANOVA revealed no significant main effects or interactions on the mean response time including observer

picture plane orientation (sphericity assumed:  $F(5, 200) = 0.335$ ,  $p < 0.889$ ,  $\eta_p^2 = 0.040$ ), avatar orientation (Greenhouse-Geisser corrected:  $F(1.486, 32.194) = 2.233$ ,  $p < 0.157$ ,  $\eta_p^2 = 0.22$ ), or the interaction of the two (Greenhouse-Geisser corrected:  $F(4.024, 32.194) = 0.915$ ,  $p < 0.468$ ,  $\eta_p^2 = 0.055$ ). There was no significant difference in mean accuracy for the between subject measure of gender ( $F(1,8) = 2.461$ ,  $p = 0.155$ ,  $\eta_p^2 = 0.24$ ).

### Discussion

The data suggests four primary findings worth noting. The first is that the detrimental effects of visual stimulus inversion on judgment accuracy exist regardless of the spatial orientation of the observer. The second is that the detrimental effects are relative to the local retinal reference frame of the observer and not a global reference frame. The third is that although judgment accuracy decreased with relative avatar angle, response times were not affected. The fourth is that the accuracy and response times at each observer angle were similar revealing no single exceptional observer orientation described by previous studies.

Figure 9 describes the mean accuracy and response time of the participants at each observer angle for all relative avatar angles. In other words the figure displays the avatar angles relative to the observer angles, i.e. an observer at  $180^\circ$  of rotation observing the avatar at  $180^\circ$  of rotation would perceive the avatar as being upside-down not right-side up. The data of all observer angles revealed the least accuracy with the longest response times when the avatar was inverted with respect to the participant's orientation suggesting that participants rely solely on a local retinal reference frame and ignore the global reference frame that they are being spatially manipulated in. In other words it suggests that visually "right" is always to the participant's right and "left" is always to the participant's left regardless of their orientation with respect to gravity.

Furthermore the lack of significance of either observer angle, avatar angle or their interaction on the participant's response times suggests that the participant's judgment confidence was unperturbed by either their own spatial orientation or the spatial demands of the task.

In the Thatcherized face study of Lobmier and Mast (2007) they reported local detriments in participant judgment accuracy in the detection of both normal and inverted Thatcherized faces when the participants were orientated at 135° of rotation within the picture plane. Other studies (Kaptein & Van Gisbergen, 2004; Mittelstaedt, 1999; Schöne, 1964; Udo de Haes, 1970; Van Beuzekom & Van Gisbergen, 2000) have suggested that participant sensory and perceptual abilities decline when the participant is rotated in the picture plane beyond 135°. Although 135° of participant rotation was not specifically examined in the present experiment, no exceptional detriments in participant judgment accuracy were found for any angle including 120° or 180° of rotation.

## EXPERIMENT 4

### Introduction

Self perceived human orientation relies to a large extent on the presence of gravity. A select number of studies have examined gravity's influence on orientation self perception mainly using a combination of earth and microgravity trials (e.g., Glasauer & Mittelstaedt, 1998a, 1998b). Self perceived rotations about an orientation in space have also been examined, yet almost exclusively from the perspective of rotational sensitivity or perceptive threshold (e.g., Clark & Stewart, 1962; Groen & Jongkees, 1946; Mergner et al., 1991). The majority of the research has originated from military or national space laboratories where knowing an individual's sensitivity to rotational movement perception is paramount.

Glasauer and Mittelstaedt (1998b) suggest that "Accurate perception of tilt, that is, perception of any change of self-orientation with respect to gravity, requires that both sources of information, the angular velocity and the changing direction of the gravito-inertial forces, are congruent" (p. 186). It may be the case that this holds true only when the perception of the vertical is required and therefore it is proposed that the perceived direction of rotational movement will be greatly perturbed even when information of both the angular velocity and the changing direction are present. In a vertical posture, where the direction of gravity is in line with the body pointing from the head to the feet, accurate self perception of one's rotational direction about the vertical plane is trivial. Accurate self perception may not be the case when the individual's global orientation with respect to gravity is altered and, therefore, the aim of the present study is to examine the accuracy of humans in the self perception of their rotational direction about the longitudinal axis in a variety of spatial orientations.

## Methods

### *Participants*

Participants were recruited from the University of Illinois community comprised of faculty, staff, and students. Participants had no known visual, cognitive, or vestibular impairments. The participants were comprised of two groups; a novice group and an expert group. The novices were defined as having never participated in the sports of figure skating, diving, gymnastics, snowboarding, and aerial ski jumping. The expert group were members of the University of Illinois men's and women's division I gymnastics team. All participants were screened to determine that they could distinguish left from right. Because of the equipment requirements all participants were 5 foot 8 inches or shorter and weighed less than 180 pounds. Twenty participants were used, 10 males (5 experts and 5 novices) and 10 females (5 experts and 5 novices).

### *Apparatus*

To manipulate the participant's orientation they were placed in a metal structure in a standing position that allowed for static picture plane angle placements in increments of 60°. The participant's feet were attached to the base using snowboard bindings, their waist was secured to the apparatus using a gymnastics spotting belt and their hands were strapped to a bar above their head with hook and loop fasteners (see Figure 10). The apparatus was comprised of two concentric rectangle metal frames supported by a larger metal frame. The participant was held in the inner most frame. The outside frame was supported in the middle by ball bearing pivot points allowing

the frame to spin 360° in the participant's picture plane. The inner frame was connected to the outer frame at the top and the bottom by ball bearing pivot points allowing the participant to spin 360° about their vertical axis. The apparatus could statically hold the participant in 1 of 6 picture plane orientations from 0 to 300 degrees in increments of 60 degrees while being able to freely rotate or twist about the longitudinal axis

The participant was manually rotated by the experimenter three times at a rate of 1 Hz. The frequency was maintained by the use of an earpiece metronome audible only to the experimenter (Steinway Metronome App on an Apple iPhone 4S).

The random observer angle generation, recording of audio response, and calculation of verbal response time was all done using a GUI program written in MATLAB (version R2009a). The verbal response time was calculated by a minimal auditory threshold response based on the volume units (VU) of the sound being recorded by a wireless lavalier microphone directly in front of the participant's mouth (Nady model Dkw-1).

### *Procedures*

Each participant was placed in the apparatus. Both the expert and novice groups were asked to report their own twisting direction from their perspective with a verbal "left" or "right" response. The participants were rotated by the experimenter 3 times at a rate of 1 Hz. Both the twisting direction and the picture plane orientation were randomly assigned based on a computer generated random pattern. Each participant completed 12 randomly assigned trials (6 angles x 2 directions). Because of the possibility for disorientation or motion sickness participants were provided frequent breaks out of the apparatus.

### *Data Analysis*

The data were compiled using MATLAB (version R2009a) and all statistical analyses were done using SPSS (version 16.0). All figures were generated using Excel (version 2007). Accuracy was determined post-hoc and defined as either 1 for a correct response (i.e. the participant reported “right” when they were actually turning to their right) or 0 for an incorrect response. The data set was compiled by taking the mean of each participant twist for every participant picture plane angle. Response time and accuracy of each participant angle (0°, 60°, 120°, 180°, 240°, 300° in the picture plane) was analyzed by means of a repeated measures analysis of variance (ANOVA) with between-subject factors of expertise and gender. Modifications to the degrees of freedom were reported as either Greenhouse-Geisser correction or Huynh-Feldt correction. The Greenhouse-Guissler correction was reported when the Huynh-Feldt epsilon was less than 0.75 (cf. Ionta et al., 2007). Post-hoc analyses were done using Bonferroni corrected main effects.

### Results

Mean accuracy and response time for both experts and novices at each of the six static picture plane orientations are illustrated in Figure 11. A repeated measures ANOVA revealed a significant between subject effect of participant expertise on the mean accuracy of determining their own twisting direction ( $F(1, 16) = 8.891, p = 0.009, \eta_p^2 = 0.36$ ) however the Huynh-Feldt corrected main effect of angle minimally influenced the accuracy ( $F(5, 80) = 2.051, p = 0.080, \eta_p^2 = 0.11$ ). There was no significant difference between males and females ( $F(1, 16) = 0.420, p = 0.526, \eta_p^2 = 0.026$ ).

A repeated measures ANOVA with a Huynh-Feldt correction revealed a significant main effect of participant angle on the mean response time ( $F(4.085, 65.361) = 4.0, p = 0.005, \eta_p^2 = 0.20$ ). Post hoc test using Bonferroni correction revealed that the mean response time at  $240^\circ$  of participant rotation was significantly greater than at  $60^\circ$  and  $300^\circ$  of rotation. The between subject measure of expertise had an almost significant effect on the response time ( $F(1, 16) = 3.786, p = 0.069, \eta_p^2 = 0.19$ ) as did the Huynh-Feldt corrected interaction of angle and expertise ( $F(4.085, 65.361) = 2.339, p = 0.063, \eta_p^2 = 0.13$ ) There was no significant difference between males and females ( $F(1,16) = 0.379, p = 0.547, \eta_p^2 = 0.023$ ).

### Discussion

Although all experts were flawless in their twisting perception, 3 of the 10 novice participants were flawless as well suggesting that although this may be predominantly a learned skill, an innate ability may exist in particular individuals. Nevertheless even in the upright condition not all novices were 100% accurate. Indeed a single participant was incorrect for one trial in the right-side up condition. Because the angle order was random for each participant, it is possible that the general disorientation of task and the order in which the participant was spatially manipulated may have contributed to the single error. Although the main effect of participant angle was not significant, 30% of the novice's judgments were at chance levels in the inverted condition and 20% of the novices were systematically wrong. The results suggest that the majority of untrained individuals may rely on a global reference frame, where the opposite direction of gravity is defined as up for sensing their own whole body rotation, rather than a local reference frame where the top of their head is defined as up. It suggests that one of the qualities that defines the expert group is the ability to rely on a local reference frame relative to their own

body regardless of the global position of their body. This notion is in line with the years of gymnastics training the experts had received to be able to make minor body form corrections while completing multiple flips and twists in space.

## SYNTHESIS OF DATA

### Introduction

Although it is not customary to combine data post-hoc from separate experiments for further analysis, in the particular case of the previous four experiments it is acceptable and valuable. The four previous studies were all repeated measures ANOVA designs with 10 gender matched participants in each group all receiving the same type of stimulus, i.e. either perceived avatar or perceived self turning directions of left or right for 6 different picture plane orientations. Indeed synthesizing the data from the four experiments lead to a much more holistic understanding of the research questions. Specifically, combining Experiments 1 and 2 distinctively addressed the relationship between a verbal response and a spatial button response in relation to ones understanding of the directions of left or right. Furthermore comparison of the data sets from Experiments 1 and 2 allowed for a more focused understanding of the nature in which reference frames were employed given the perceptually complex nature of the tasks. Because both Experiments 1 and 3 relied on the same stimulus and required the same verbal response from the participants, the synthesis of Experiments 1 and 3 provided a means to address the differences between participants in a seated upright position and participants in a standing position both upright and inverted. The synthesis of Experiments 1 and 4 directly addressed the relationship of the perception of an external rotating body and the perception of one's own body rotating. Moreover combining Experiments 1 and 4 directly attended to the role of experiential expertise in both an observational and experiential perceptual task.

### Button Pattern Congruency and Verbal Response

It was proposed that a possible secondary strategy was employed by some of the participants in Experiment 2. The synthesis of Experiments 1 and 2 may help tease apart which button pattern data set from Experiment 2 most closely resembles the verbal response data set from Experiment 1. The synthesis also lends further evidence to suggest the use of an external reference frame in Experiment 2. Both the mean accuracy and response time data sets from Experiment 1 were presented as a fifth condition in Experiment 2 (4 button pattern conditions plus 1 verbal condition). The same statistical measures performed in Experiment 2 were performed again with the fifth verbal response condition included.

Mean accuracy and response time for all four response patterns of Experiment 2 including the verbal responses from Experiment 1 at each of the six static picture plane orientations are illustrated in Figure 12. A repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on mean accuracy ( $F(2.460, 221.391) = 13.464, p < 0.001, \eta_p^2 = 0.13$ ). Post hoc tests using Bonferroni correction revealed that the mean accuracy at the inverted avatar angle ( $180^\circ$  of rotation) was significantly different from all other angles. The between subject measure of response type had a significant effect on the mean accuracy ( $F(4,90) = 3.304, p = 0.014, \eta_p^2 = 0.13$ ). Post hoc tests using Bonferroni correction revealed that the verbal responses were significantly different from the button response pattern where the right button corresponded to a right twist ( $p = 0.012$ ). There was also a significant interaction between avatar picture plane orientation and response type on the mean accuracy ( $F(9.840, 221.391) = 4.796, p < 0.001, \eta_p^2 = 0.18$ ). No other interactions were significant.

The repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on the mean response time ( $F(3,203, 288.315) = 55.309, p < 0.001, \eta_p^2 = 0.38$ ). Post hoc test using Bonferroni correction revealed that the mean response time at the inverted avatar angle ( $180^\circ$  of rotation) was significantly different from all other avatar picture plane angles ( $p < 0.001$  for all angles). There was no significant difference for the between subject measure of response type on the mean response time ( $F(4,90) = 1.118, p = 0.353, \eta_p^2 = 0.047$ ) however the interaction between avatar picture plane orientation and response type approached significance ( $F(12,814, 288.315) = 1.710, p = 0.059, \eta_p^2 = 0.071$ ). There was a significant effect of gender ( $F(1, 90) = 9.950, p = 0.002, \eta_p^2 = 0.10$ ) where male's average response time (2030 ms) was shorter than female's average response time (2740 ms). No other interactions were significant.

The mean accuracy from the verbal responses was only statistically different from the right button equals right turn pattern. It was assumed that this button pattern was the most congruent and therefore the pattern that would most closely resemble the verbal responses from Experiment 1. The mean accuracy of the right button equals right turn pattern was inverted when compared to the other 3 response button response patterns and the verbal response pattern. This is most likely due to the use of the previously outline external reference frame strategy that has been argued as a tool for many of the participants in Experiment 2. When the avatar was upright a right turn would cause the face of the avatar to travel from the right side of the computer screen to the left thus eliciting a left button push and an incorrect response. When the avatar was inverted the same right turn would cause the face of the avatar to travel the opposite direction across the computer screen thus eliciting a right button push and a correct response. This was not absolute as many of the participants still relied on the original instructions and strategy yet it

occurred frequently enough to produce mean accuracies illustrated as an inverted U in Figure 12. It is unclear however why individual's judgments during the right button equals right turn response pattern were more susceptible to the external reference frame strategy than in the other conditions.

There was no significant difference in the response times across the 4 button response patterns of Experiment 2 and the verbal responses of Experiment 1 suggesting that the inverted conditions across all patterns was equally cognitively demanding.

#### Upright and Picture Plane Manipulated Observer Orientations

Mean accuracy and response time for the upright and inverted conditions of Experiment 3 (standing position in the rotating apparatus) and the data from the novice group of Experiment 1 (sitting upright) at each of the six static picture plane orientations are illustrated in Figure 13. A repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on mean accuracy ( $F(2.532, 60.777) = 8.983, p < 0.001, \eta_p^2 = 0.27$ ). The between subject measure of body position had a significant effect on the mean accuracy ( $F(2,24) = 4.305, p = 0.035, \eta_p^2 = 0.26$ ) where the participants in the sitting condition observing the inverted avatar stimulus were correct only about half as often as either of the apparatus conditions observing the same stimulus. At all avatar angles the mean accuracy of the participants in both apparatus conditions was greater than the mean accuracy of the participants in the sitting condition. A repeated measures ANOVA with a Greenhouse-Geisser correction revealed a significant effect of avatar picture plane orientation on the mean response time ( $F(1.819, 43.654) = 6.828, p < 0.003, \eta_p^2 = 0.22$ ). Females were significantly slower to respond

than males by an average of 480 ms for all 3 conditions ( $F(1, 24) = 7.961, p = 0.009, \eta_p^2 = 0.25$ ). There were no other significant interactions.

For every picture plane angle participants in Experiment 1 were less accurate than the participants in Experiment 3 for both the inverted and the upright conditions. Furthermore participants in Experiment 1 were nearly half a second slower to respond during the condition where the avatar was inverted with reference to the participant. It is proposed that participants in Experiment 3 were better at the task because of an immediate and salient spatial calibration inherent in the nature of the task. Because the conditions were randomly assigned in both experiments, the participants in Experiment 3 had the advantage of being spatially manipulated through a series of picture plane orientations throughout the experiment essentially allowing some form of spatial calibration to aid in their perceptual abilities during the task. Because the participants in Experiment 3 were able to experience all of the picture plane orientations as the task was being performed, the participants were provided a wealth of information unavailable to the always upright participants of Experiment 1. The participants in Experiment 1 were seated and the participants in Experiment 3 remained in a standing position throughout the testing. The avatar was also displayed in a standing position at it is unclear whether or not the change in posture between experiments contributed to the discrepancy between the mean accuracies of the two experiments.

#### Perceived Avatar Rotation and Perceived Self Rotation

Mean accuracy and response time for the novice and expert groups of Experiment 1 (avatar perception) and the novice and expert groups of Experiment 4 (self perception) at each of the six static picture plane orientations are illustrated in Figure 14. A repeated measures ANOVA

with a Greenhouse-Geisser correction revealed a significant effect of avatar/participant picture plane orientation on mean accuracy ( $F(3.386, 108.344) = 14.035, p < 0.001, \eta_p^2 = 0.31$ ). The between subject measure of avatar perception verses self perception had a significant effect on the mean accuracy ( $F(1, 32) = 9.835, p = 0.004, \eta_p^2 = 0.24$ ) as did the interaction of picture plane angle and perceptual stimuli ( $F(3.386, 108.344) = 3.593, p = 0.013, \eta_p^2 = 0.10$ ). Expertise also had a significant effect on the mean accuracy ( $F(1, 32) = 6.352, p = 0.017, \eta_p^2 = 0.17$ ) where the novices during the self perception task performed similar to both the novice and experts during the avatar perception task. The experts however never made an error in the self perception task. There were no other significant interactions.

A repeated measures ANOVA with a Huynh-Feldt correction revealed a significant effect of avatar/participant picture plane orientation on mean response time ( $F(4.116, 131.705) = 8.859, p < 0.001, \eta_p^2 = 0.22$ ). The between subject measure of avatar perception verses self perception had a significant effect on the mean response time ( $F(1, 32) = 46.499, p < 0.001, \eta_p^2 = 0.59$ ) as did the interaction of picture plane angle and perceptual stimuli ( $F(4.116, 131.705) = 1.459, p < 0.001, \eta_p^2 = 0.23$ ) where both the novices and the experts in the self perception experiment were nearly three times faster at responding than when observing the avatar. There were no other significant interactions.

While the experts in Experiment 4 were flawless in their performance, the novice participants of Experiment 4 were equally inaccurate as both the novice and expert observers in Experiment 1 with a mean of 65% accuracy during the inverted condition. Exclusively for the novices both the observer and the participant (i.e. both the avatar observer from Experiment 1 and the self perceiver from Experiment 4), were in agreement and equally poor in their judgments. The data therefore suggests that for an untrained participant during the perception of

a rotating human form there is little difference between the accuracy of one's visual spatial perception and one's somatosensory spatial perception. Furthermore something in the selection or training of the college level gymnasts allows a greater separation between these two perceptual mechanisms. While the visual perception of another human form rotating is not influenced by expertise, somatosensory and perhaps visual perceptual abilities of an accomplished gymnast's own rotation becomes highly tuned.

## GENERAL DISCUSSION

### Mental Rotation

Of great importance in mental rotation tasks is the strategy that is employed to accurately mentally rotate an object. The data from Experiment 3 suggests that observers rely almost exclusively on an egocentric reference frame when being spatially manipulated. The global orientation had little to no effect on the perceptual abilities of the observers and merely the angle of discrepancy between the observer and the avatar was relevant. Supportive results were shown by Chang, Harris and Troje (2010) where the most accurate and fastest responses in a mental rotation task were shown when the stimulus and observer were locally congruent independent of their global orientation with respect to gravity. The dependence on a local egocentric reference frame was also shown in infants as young as three months old in a habituation-dishabituation procedure where the infants' length of gaze was measured in a novelty detection task (Kushiro, Taga, & Watanabe, 2007).

Participants in Experiment 3 were significantly more accurate than the participants in Experiment 1 and it was hypothesized that either observer body position or a learning effect due to the randomizations of the trials in Experiment 3 accounted for the differences. Other researchers have found a link between body anatomical position and mental rotation abilities as well. Ionta, Fourkas, Fiorio and Aglioti (2007) showed that the ability to accurately perceive hand laterality was influenced by the anatomical position of the observer's hands, specifically the greatest detriments in accuracy were found when the observer's hands were behind the back with the fingers interlocked. No changes in accuracy were found however when varying the hand

position in the accurate perception of foot laterality suggesting a close link between the anatomical position of the specific body part being observed.

With the exception of Experiment 2, which was in part a spatial mapping task between the button response pattern and the stimulus, no sex differences were found in either accuracy or response time. Historically research has shown sex differences in mental rotation task with males consistently outperforming females (Linn & Peterson, 1985; Voyer, Voyer, & Bryden, 1995). Many researchers have argued that the differences were due to biological or hormonal factors (Halari, Hines, Kumari, Mehrotra, Wheeler, Ng, & Sharma, 2005; Hausmann et al., 2000). More recently Nazareth, Herrera & Pruden (2013) were able to explain, in part, the sex differences in mental rotation tasks as a function of one's previous experiences with spatially related activities. Although no direct evidence exists in the four experiments presented, it may be the case that Experiment 2 tapped into a unique set of experiences not referenced in the other three experiments allowing the males to outperform the females on the button pushing task.

### Perception of Biological Motion

The errors displayed in the observation of the inverted avatar rotation highlights the question of what the observer is actually observing. Sumi (1984) presented inverted point light movement patterns to participants and although they were able to recognize inverted walking, the observers reported that the point light walkers appeared to be moving in a very strange manner. Because the upper and lower limbs were inverted the participants perceived a biologically improbable scenario of a strange upright walker over the alternative of an inverted walker. Based on Sumi's data one could surmise that when given a choice between accurately perceiving the biology or accurately perceiving the motion of an inverted point light presentation, an observer

regularly chooses the motion. It may be the case that during the inverted conditions of the rotating avatar the participants who had the greatest difficulty also relied on the motion over the biology. Going from upright to inverted the absolute direction of rotation of an object is unchanged. In other words because a rock has no apparent top or bottom a perceived left spin in one orientation would not appear to be in the opposite direction when inverted. This is not true with a human figure where a clear top, the head, and bottom, the feet, are well defined and when inverted rotation is presented the absolute direction of rotation of the object as a whole is opposite the direction of rotation of the actual avatar.

Although humans have a well defined top and bottom it is unclear what anatomical landmarks were salient to the observer in either accurate or inaccurate perception of the rotating avatar. Many of the observers reported using the shoulders, hips or head and it may have been the case that other anatomical landmarks of the avatar provided no additional information and may have even confounded the issue. In 2006 Troje and Westhoff presented inverted point light displays where many of the points were scrambled and the data suggested that only the feet were critical in accurately determining the direction of travel of humans and animals. Troje and Westhoff hypothesized that the data presented evidence for a perceptual system tuned to the recognition of upright limb movement during locomotion.

In contrast Murofushi, Ono, Sato and Kitazaki (2012) presented inverted point light display walkers and avatar walkers traveling diagonally across a computer screen with variations in head direction. The authors reported that the perceived direction of travel was dependent on the direction of the head and the modulation was greater for point light displays than for avatar presentations.

Another concern beyond just the anatomical landmarks is the initial spatial orientation of the avatar. In all cases the avatar was facing the observer at the onset of stimulus presentation and it may be the case that changing the initial orientation of the avatar, namely having the rotation start with the avatar facing away, could have greatly impacted the accuracy of the observers. May and Wendt (2012) determined that lateral judgments of a left or right hand are faster and more accurate when presented in a back-facing view when compared to a front-facing view. Point light displays by their very nature void of depth cues and Vanrie, Dekeyser and Verfaillie (2004) showed that observers are more likely to assume a point light display if facing them rather than facing the opposite direction. This however has been subsequently shown to be dependent on the gender of the point light walker (Brooks, Schouten, Troje, Verfaillie, Blanke, & van der Zwan, 2008).

### Visual Perception

Because of the long response times on the order of seconds, it could be argued that all four experiments demonstrated evidence for an indirect approach towards visual perception. Although the avatar was a three-dimensional rendering, it was displayed on a two-dimensional computer screen and therefore the observer was required to recreate the missing data that was contained in the projection. From both an inferential and organizational indirect visual perception approach there were two inherent difficulties in the reconstruction; the dynamic rotation of the avatar and the picture plane orientation of the avatar. Both provided a challenge in concert in perceiving the veridical.

The avatar appeared to the observers at the same time as the initiation of rotation and as such, in contrast to Cooper and Shepard (1973), there was no visual priming available to the

participants with regards to the picture plane orientation. In some sense the observers were playing catch-up throughout the entire stimulus as they were trying to reconstruct the missing data from the two-dimensional projection. The same amount of visual information was present at all angles and the only component that varied was the direction of movement as it passed across the retina. In upright and inverted conditions the direction of movement traveled exclusively in a left or right direction across the retina and at all other angles the movement traveled across the retina at some oblique angle. In the case of Experiment 1, in the upright conditions the participant could perform a simple cognitive task to convert the direction of movement across the retina to a verbal response. As an example, if a participant experienced motion from the left side of their retina to their right, then a transformation could be performed to accurately report a left turn by the avatar. This is a regular and natural transformation based on contralateral mirroring used in everyday human interactions such as shaking hands and hugging. This has been shown in children as young as 5 years old when imitating the spatial location of an arm action (Bekkering, Wohlschlagel, & Gattis, 2000). However, when the avatar is inverted, what may have been a normal transformation becomes compounded because the left and right anatomical locations are reversed. In contrast to the previous example, when the avatar was inverted if a participant experienced motion from the left side of their retina to their right, then the regular contralateral transformation could be performed and additional cognitive processes may be required to try to report the veridical. From either an organizational or inferential approach, the inverted conditions are taxing to what would customarily be either the best or most probable perceived action.

An integral part of Gibson's (1979) theory of direct visual perception is the extent to which evolution has shaped humans perceptual abilities. Extending this notion would presume

that humans have evolved to interact with the world in an upright position (Neimitz, 2010) and from a direct perceptual perspective one might assume that placing participants in historically unnatural orientations as in Experiment 3 would reveal greater perceptual errors. This was not the case however as participants showed greater accuracy and faster response times.

The primary conjecture of Gibson's (1979) ecological approach to direct perception is that visual perception is natural and immediate and no additional unconscious inferences are required. It may be the case that the participants relatively slow response times (500 ms to 3500 ms) were a function of the stimulus length and not the participant's perceptual abilities. In all experiments a three second stimulus was provided and it may be inappropriate to assume evidence against a direct perception approach because of the stimulus length presented.

Another champion component of Gibson's (1979) theory is the inherent link between perception and action and it is appropriate to argue that a verbal response, especially a response requiring the generation of a spatial word, is not a direct action based on a visual stimulus and therefore not a sincere test of direct perception. This may be the case in Experiment 2 also as the button combinations used may have required additional cognitive demands beyond just the perception/action synergy proposed by Gibson. Indeed the work of Hippler, Klopfer, Leventhal, Poor, Klein, & Jaffee (2011) on a virtual spatial manipulation task showed that response times were dependent on the tool used to provide the response. The authors showed a significant reduction in response times when a touch screen was used rather than a computer mouse click or a button push.

The final integral component of Gibson's (1979) theory of direct perception is that the observer's success is dependent on the active exploration of the environment. Möhring and Frick (in press) showed that 6 month olds' abilities to discriminate mentally rotated objects to either a

possible or impossible position was highly dependent on their access to actively explore the object prior to testing. Because of the random assignment of observer picture plane angles used in Experiment 3, one could argue that the participants in Experiment 3 were faster and more accurate than the participants in Experiment 1 because they were afforded the opportunity to actively explore their spatial environment. If humans were evolutionarily developed to live right-side-up (Niemitz, 2010) then it is not a stretch to argue that our visual system was developed to perceive predominantly upright human action therefore making active exploration of a spatial environment critical in determining the veridical in Experiment 3.

### Conclusion

The primary goal of the four experiments was to understand the extent that humans are capable of accurately perceiving both their own rotations and the rotations of others and how spatial manipulations of the actor and the perceiver affect the perception of the action. In general all four experiments support the global hypothesis that the accurate perception of a rotating human form, either one's own body or that of an avatar on a computer screen, is inherently challenging and cognitively demanding. Even under the simplest conditions of Experiment 1, participants on average were only 84% accurate at determining the correct twisting direction of an upright avatar and it took an average of 2200 ms to respond. In contrast Shepard and Metzler (1971) showed average response times of 4500 ms when the comparable three-dimensional shapes were rotated 180° apart from each other in the picture plane, however even then participants eventually got the correct answer. Although the mechanisms may be different, it is likely that participants in the present four experiments have either convinced themselves of a believed correct response or essentially gave up and resorted to a guess, especially in the inverted

conditions evident in the overwhelming results across experiments where participants had a mean accuracy close to 50%.

As a whole the results from the present 4 experiments are consistent with the breadth of research related to the spatial perception of both objects and biological motion. It is not clear however that a separation between the perceived action and some form of labeling strongly exists (Crawford, Regier, & Huttenlocher, 2000; Hayward & Tarr, 1995; Kemmerer, 1999; Tversky & Lee, 1998). After all there are many individuals who have a hard time remembering left from right but have no trouble navigating to familiar or even new places. The basic notion is that as the angle of discrepancy between either two objects or the observer and a stimuli increase, the accuracy decreases and the response time increases placing greater demands on the perceptual system. Rarely however have such gross inaccuracies in judgment been displayed with such a fundamental task of the choice of left or right. It is possible that the actual act of labeling the action, either with the words “left” or “right”, or with the button patterns such as up or down is clouding the issue of the visual perception of biological motion.

A dominant number of studies (e.g., Ionta et al., 2007; Lewis, 2001; Sayeki, 1981; Shepard & Metzler, 1971) have used a same or different comparison paradigm to remove the use of language and avoid the complexity all together of integrating language. It may have proved significant to consider using a similar paradigm where the participant observed two animated figures in the same or different picture plane orientations turning and was asked to report whether the two avatars were turning in either the same or opposite directions. Another approach would have been to provide the participant with a physical model of the animated figure and their task was to simply rotate the model in the same direction as the animated figure thus reducing the use of language. This awaits further experimentation.

Experiment 2 was an attempt to remove the concept of language, or at least to remove the immediate use of the words “left” or “right” and to introduce the use of reference frames in the spatial perception of biological motion. Although the pattern of right button corresponding to a right twist was hypothesized to be the most congruent and intern the best representative of the veridical, in actuality the right button to right twist pattern was essentially the opposite of the verbal responses. The button response pattern of left button equals right twist was the most similar to the verbal responses. The data from Experiment 2 suggests that external reference frames became a competing tool in the judgments made by the participants. Although the room was completely dark, the computer screen produced enough light to make out the basic room outlines which may have been sufficient to dominate the strategy employed. A noteworthy validation of the data may have been to recreate the study using a personal display device that occluded all peripheral vision. The same tool could have been used in Experiment 3 as well.

The experts in Experiment 4 were superior in their judgment with relatively fast response times. The data suggests that the expert’s training played an essential role in their ability to distinguish their own left verses right turns. It is ambiguous however what perceptual mechanisms aided in their accurate judgments. Because the participants had use of vision, it is vague whether Experiment 4 was really a visual perception task or a combination of somatosensory and vision. The goal was to match the environment to their expertise as closely as possible and mirroring the experiment without vision may have provided further insights into the nuances of the expert group’s actual expertise.

The expert groups were comprised of division I college gymnasts and were arguably considered experts in the action of spatial whole body rotations as opposed to experts in the observation of spatial whole body rotations such as gymnastics coaches or judges who spend

considerably more time observing such movements. The synthesis of Experiments 1 and 4 speaks directly to this distinction where there was no significant difference between the experts and novices in the observational task of Experiment 1 yet stark contrasts existed between the experts and novices in Experiment 4 where the goal was to accurately determine their own movement. Neither experiment utilized expert observers such as gymnastics coaches or judges and a more complete understanding of the specificity of perceptual expertise may have been developed with the use of such expert groups.

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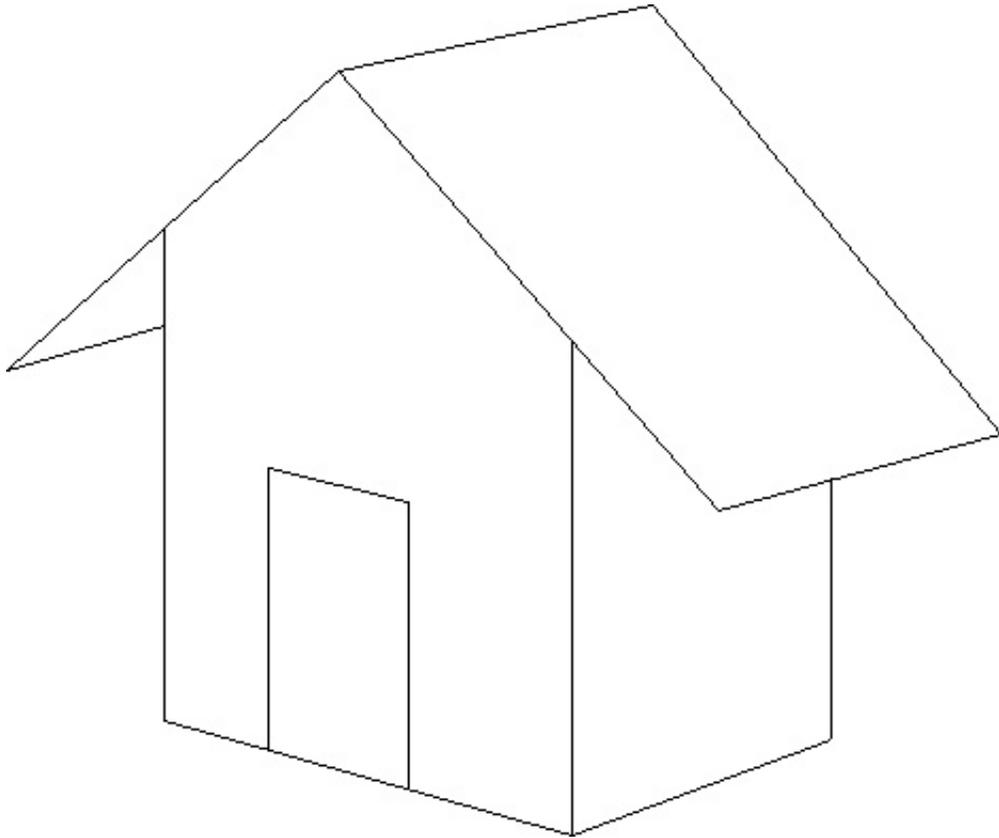
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## FIGURES



*Figure 1.* Line drawing illustrating the possible interpretations of visual stimuli from either a direct or indirect perceptual perspective.



*Figure 2.* Figure of the animated rotating avatar. The avatar was produced using Bryce 5.0, a 3-D animation authoring software program. The avatar was 220 pixels wide by 700 pixels tall and was displayed on a Dell E197FP 19 inch TFT monitor with the resolution set at 1024 pixels wide by 768 pixels tall.

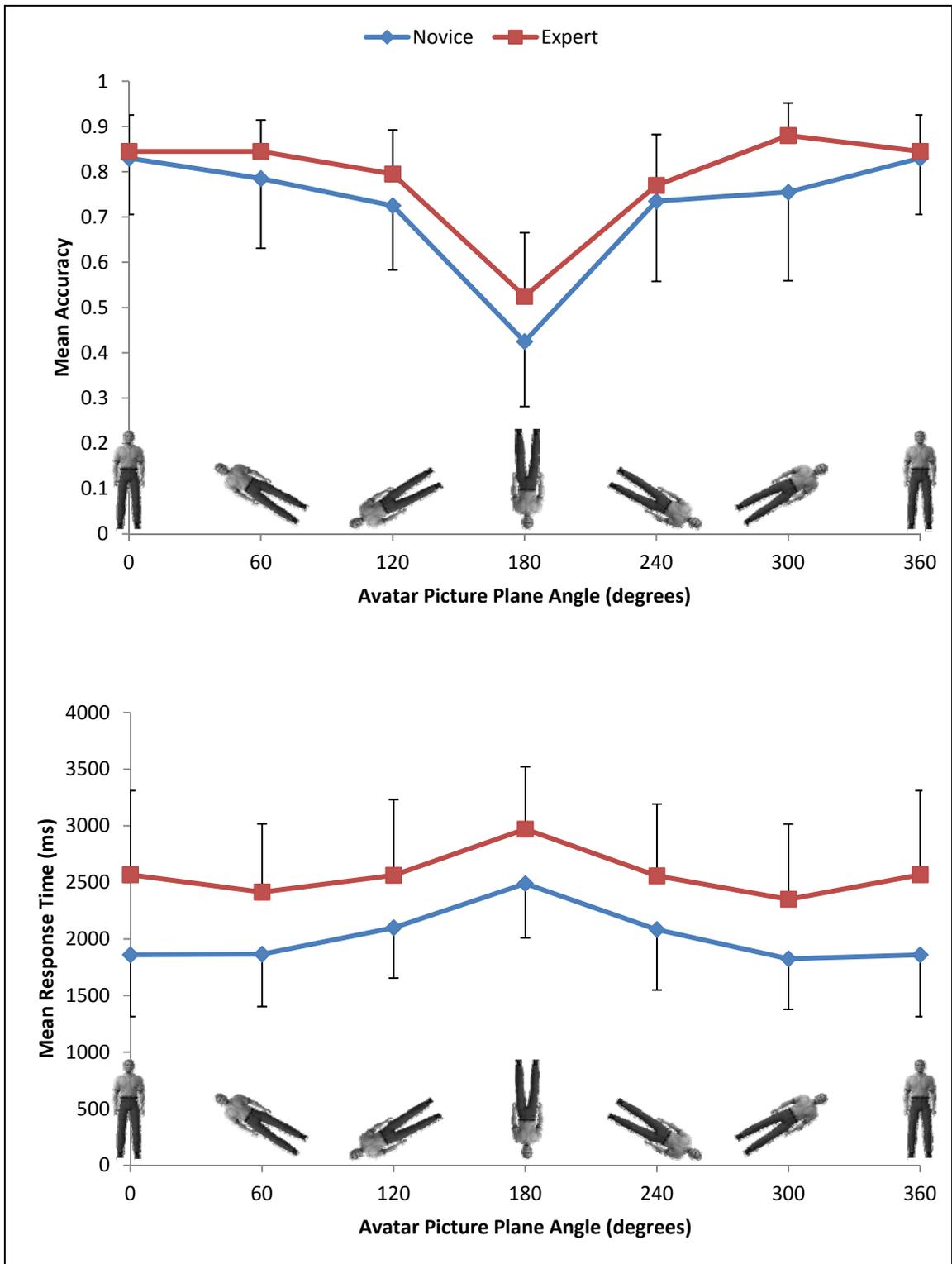
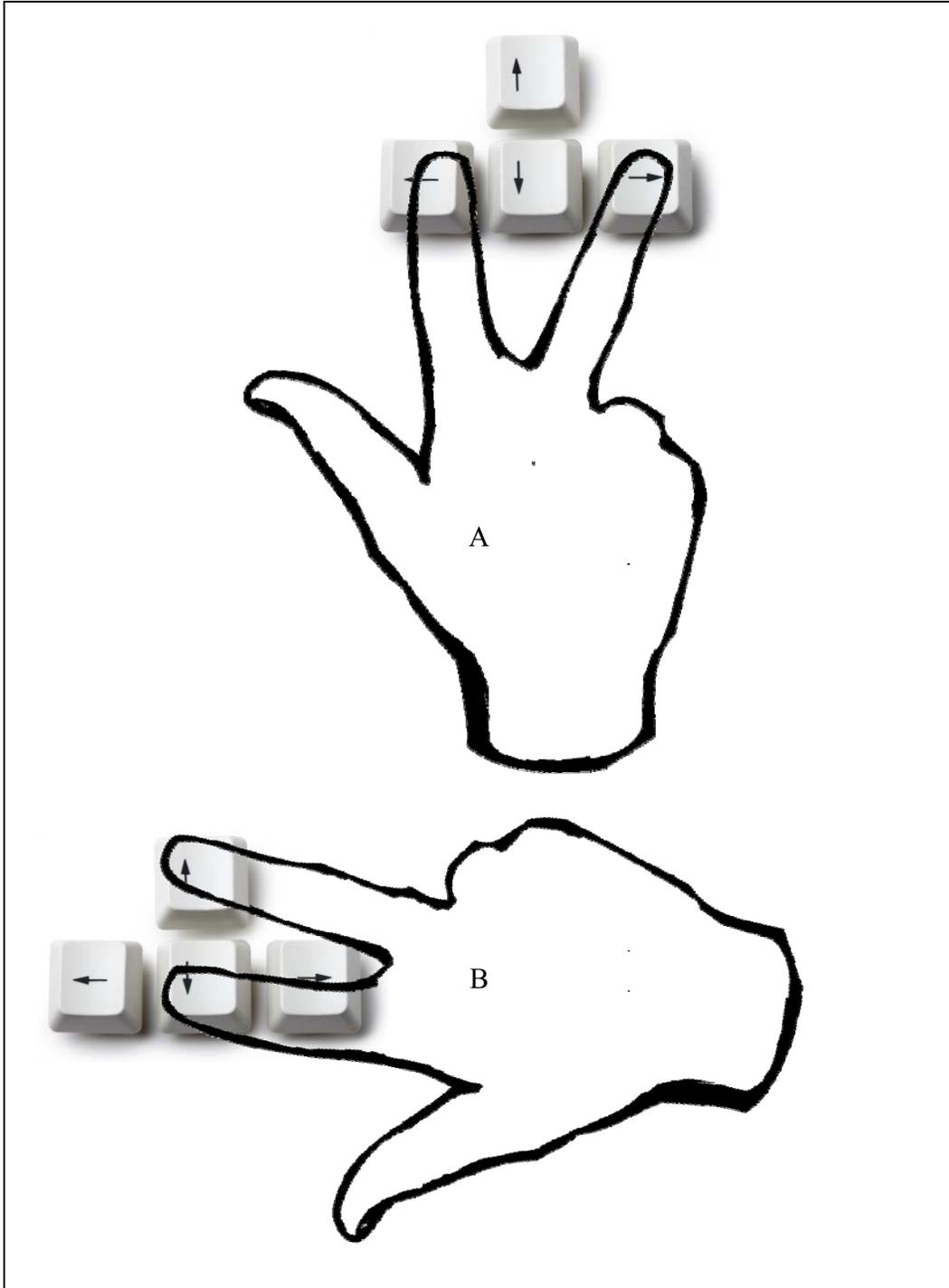


Figure 3. Mean accuracy and response time for both experts and novices at each of the six static picture plane orientations from Experiment 1.



*Figure 4.* Participant hand placement for the arrow button responses in experiment 2 on a Logitech USB keyboard (model K120). All participants were asked to use their right hand oriented in position A for button response patterns 1 & 2 and oriented in position B for button response patterns 3 & 4.

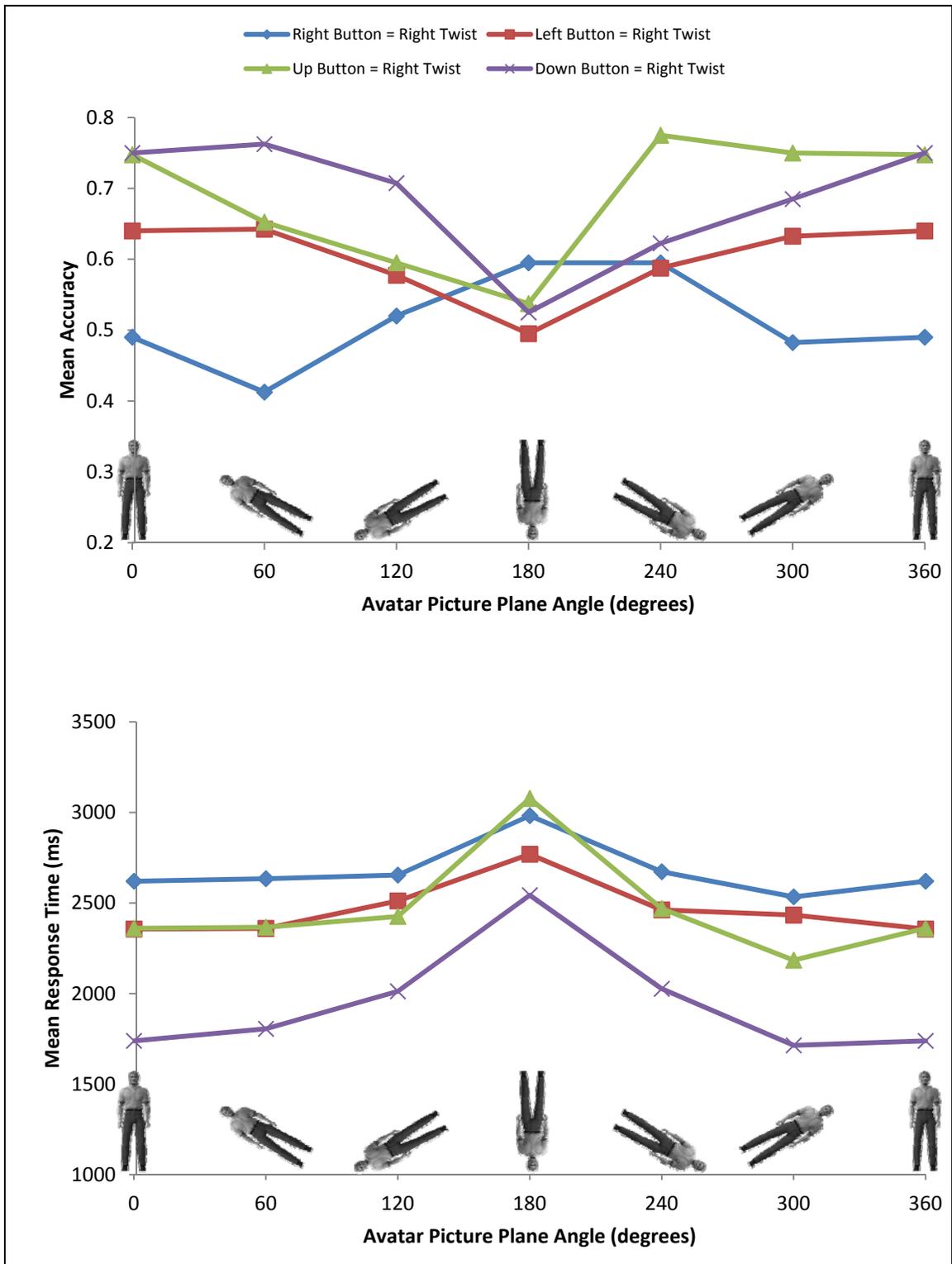


Figure 5. Mean accuracy and response time for all four response patterns at each of the six static picture plane orientations from Experiment 2.

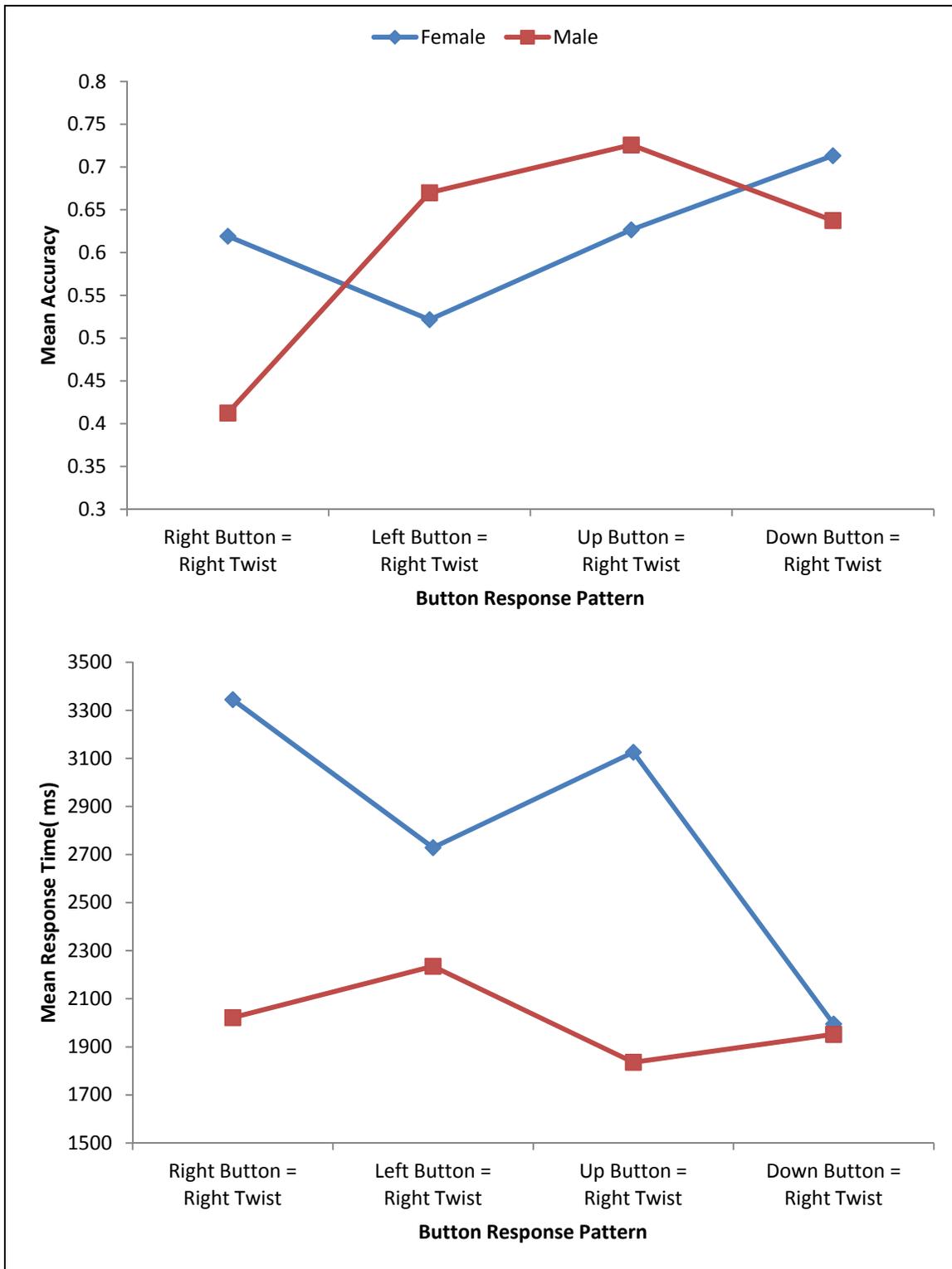


Figure 6. Accuracy and mean response time separated by males and females averaged over all 6 picture plane angles for each of the button response patterns from Experiment 2.

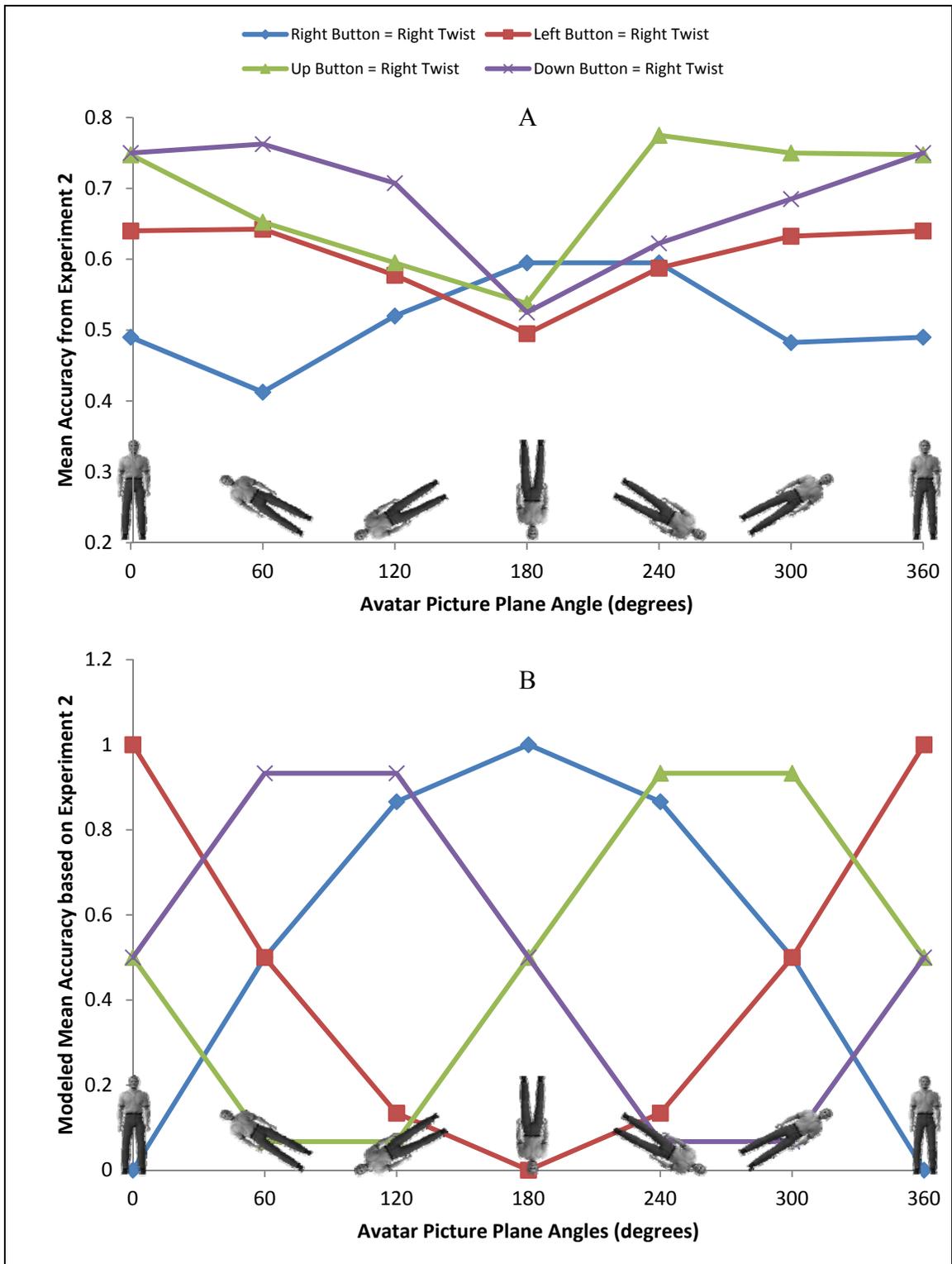
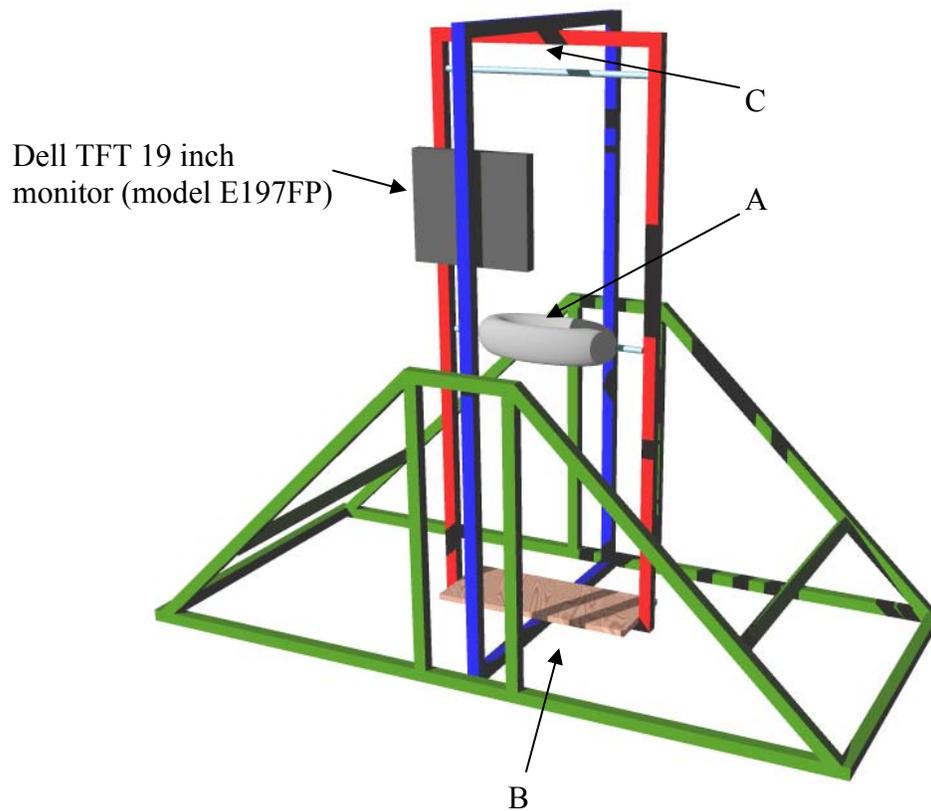


Figure 7. Mean accuracy (A) and modeled accuracy (B) for all four response patterns at each of the six static picture plane orientations from Experiment 2.



*Figure 8.* Figure of the observer rotating apparatus. The inner frame (red) secures the participant and the outer frame (blue) can be locked in static increments of  $60^\circ$  of rotation in the cartwheel plane. The participant is secured to the apparatus primarily at the waist by a gymnastics spotting belt (A) designed to support human weight. Their feet are kept in place with snowboard bindings (B) attached to the base of the inner frame. The participant's hands are secured to a metal bar at the top of the inner frame (C) with hook and loop fastener weightlifting straps. Both the feet and hand supports are used to maintain body alignment and the majority of the load is placed on the spotting belt.

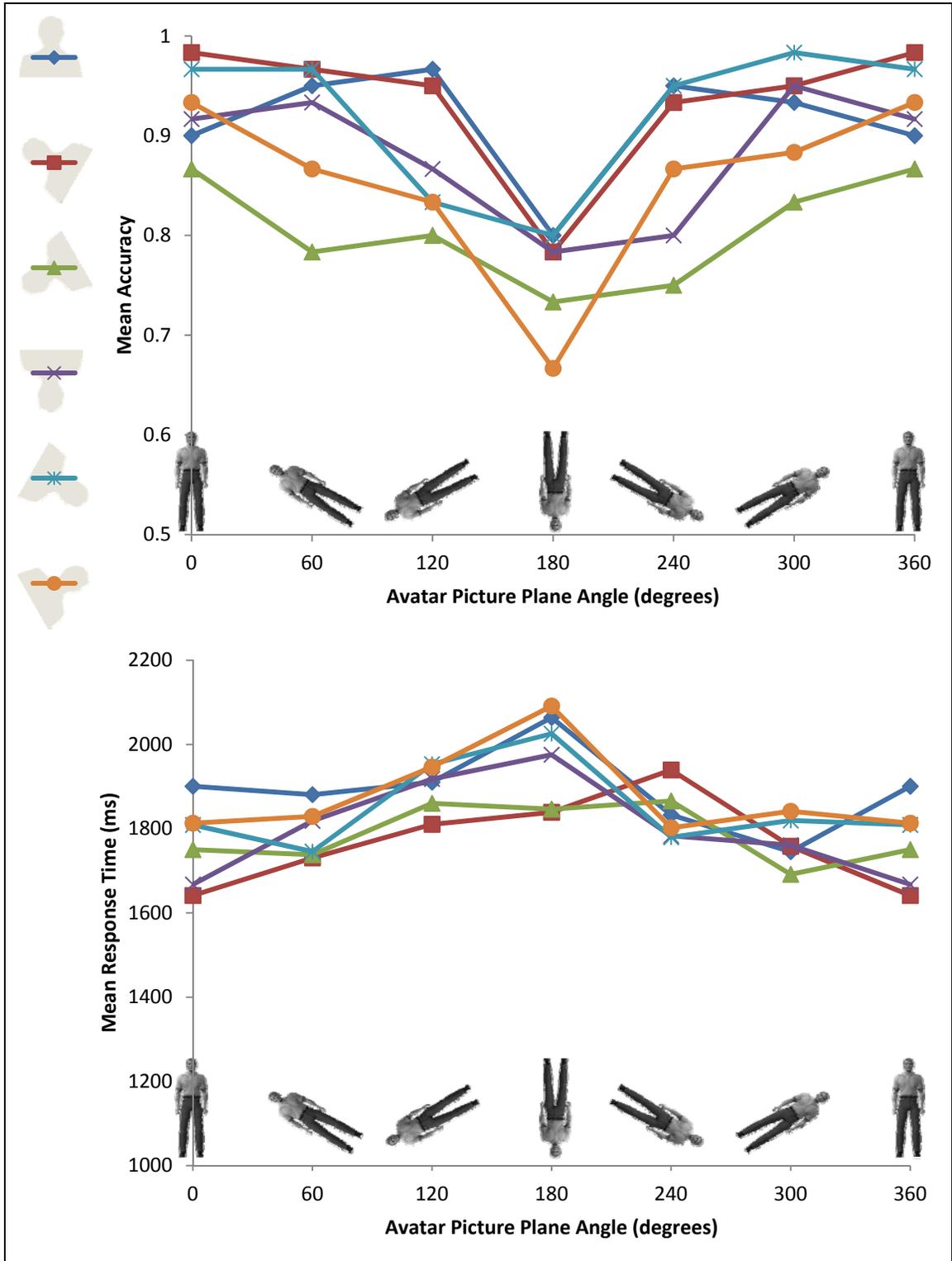
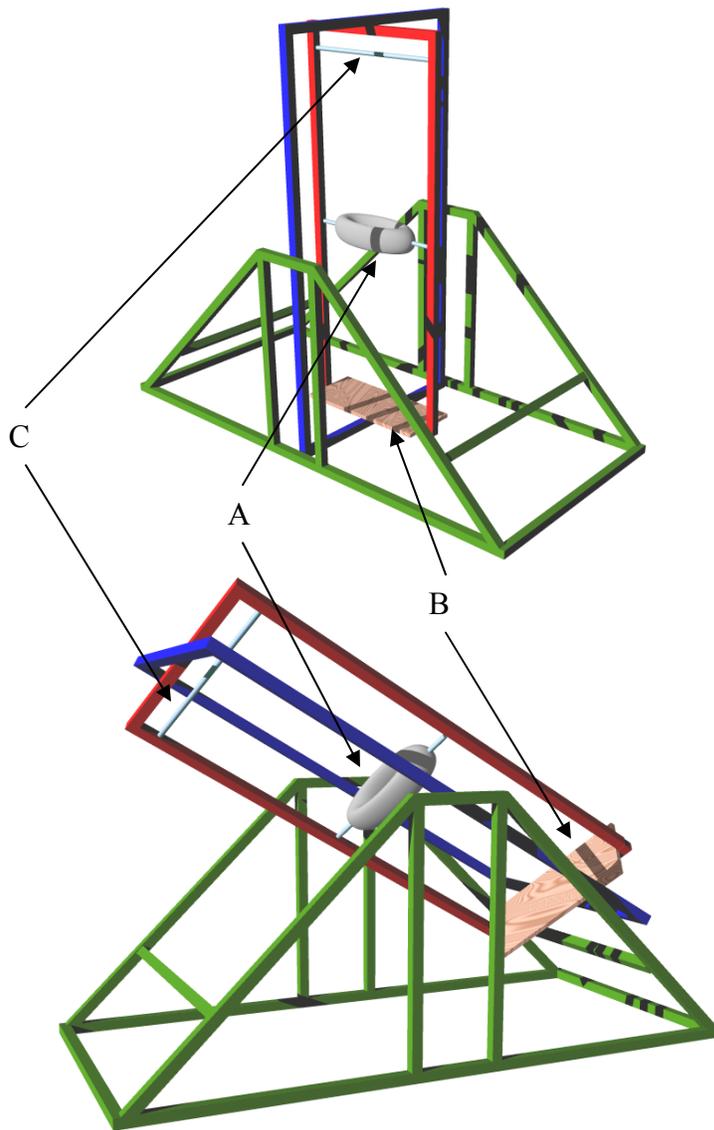


Figure 9. Mean accuracy and response time of every observer picture plane orientation for each avatar orientation. The legend corresponds to each observer picture plane angle of 0°, 60°, 120°, 180°, 240° and 300° for Experiment 3.



*Figure 10.* Figure of the twisting apparatus in free rotation mode. The inner frame (red) provides revolutions in the “twisting direction.” The outer frame (blue) was locked in static increments of  $60^\circ$  of rotation in the cartwheel plane. The participant is secured to the apparatus primarily at the waist by a gymnastics spotting belt (A) designed to support human weight. Their feet are kept in place with snowboard bindings (B) attached to the base of the inner frame. The participant’s hands are secured to a metal bar at the top of the inner frame (C) with hook and loop fastener weightlifting straps. Both the feet and hand supports are used to maintain body alignment and the majority of the load is placed on the spotting belt.

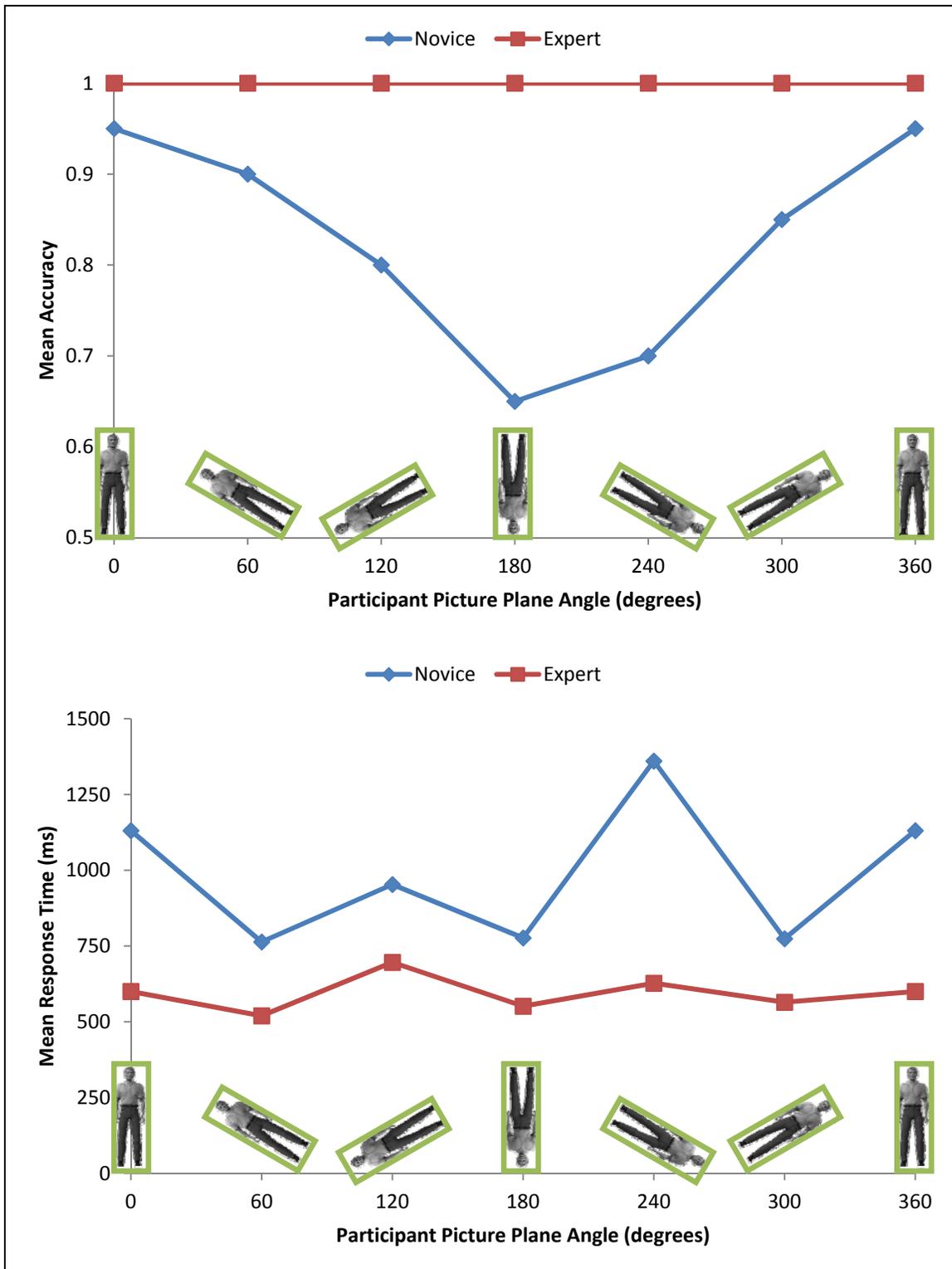


Figure 11. Mean accuracy and response time of the participants determining their own twisting direction for both experts and novices at each of the six static picture plane orientations from Experiment 4.

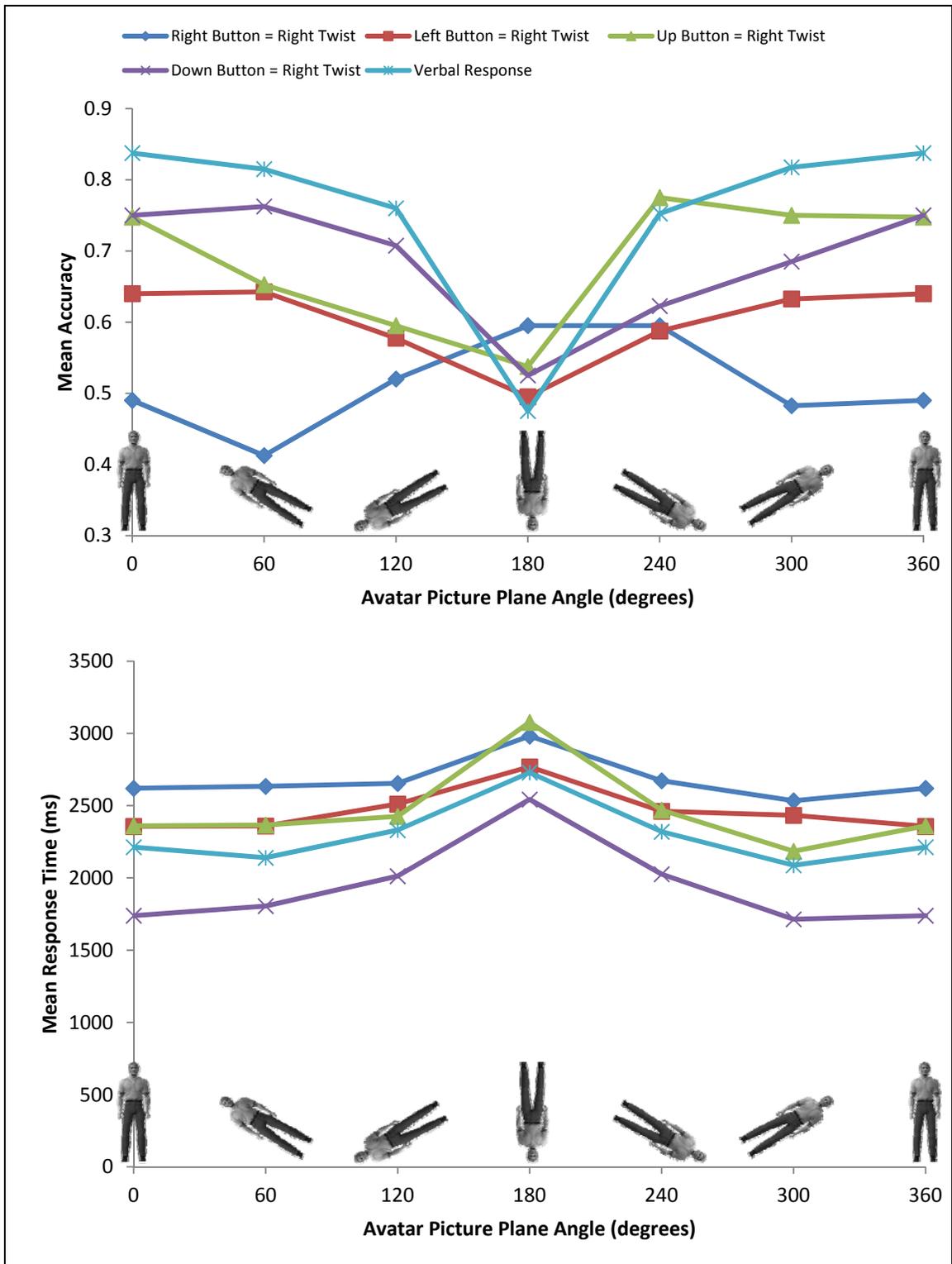


Figure 12. Mean accuracy and response time from combined experiments 1 and 2 for all four response patterns and verbal responses at each of the six static picture plane orientations.

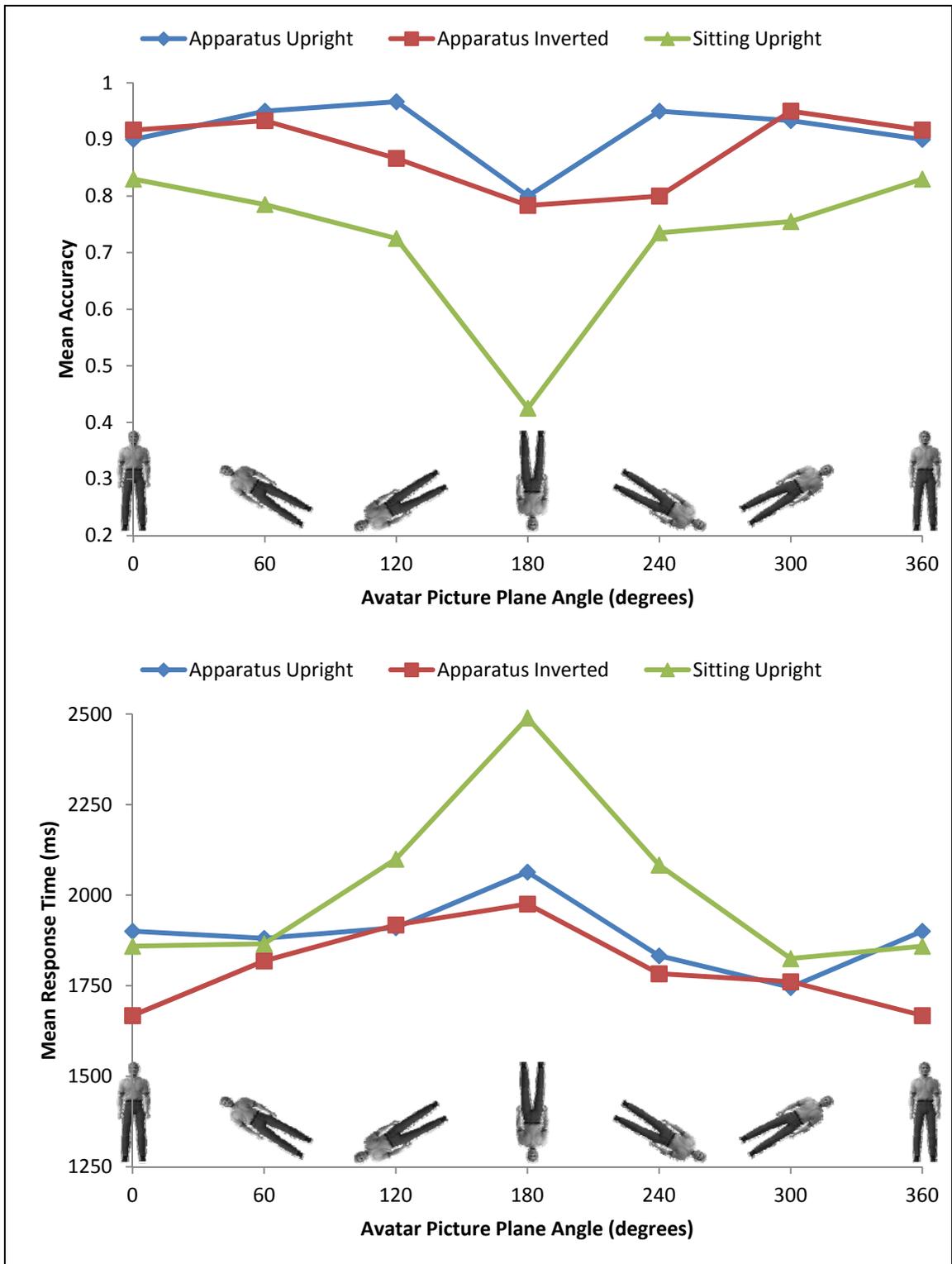


Figure 13. Mean accuracy and response time from the upright and inverted conditions of Experiment 3 and the novice group of Experiment 1.

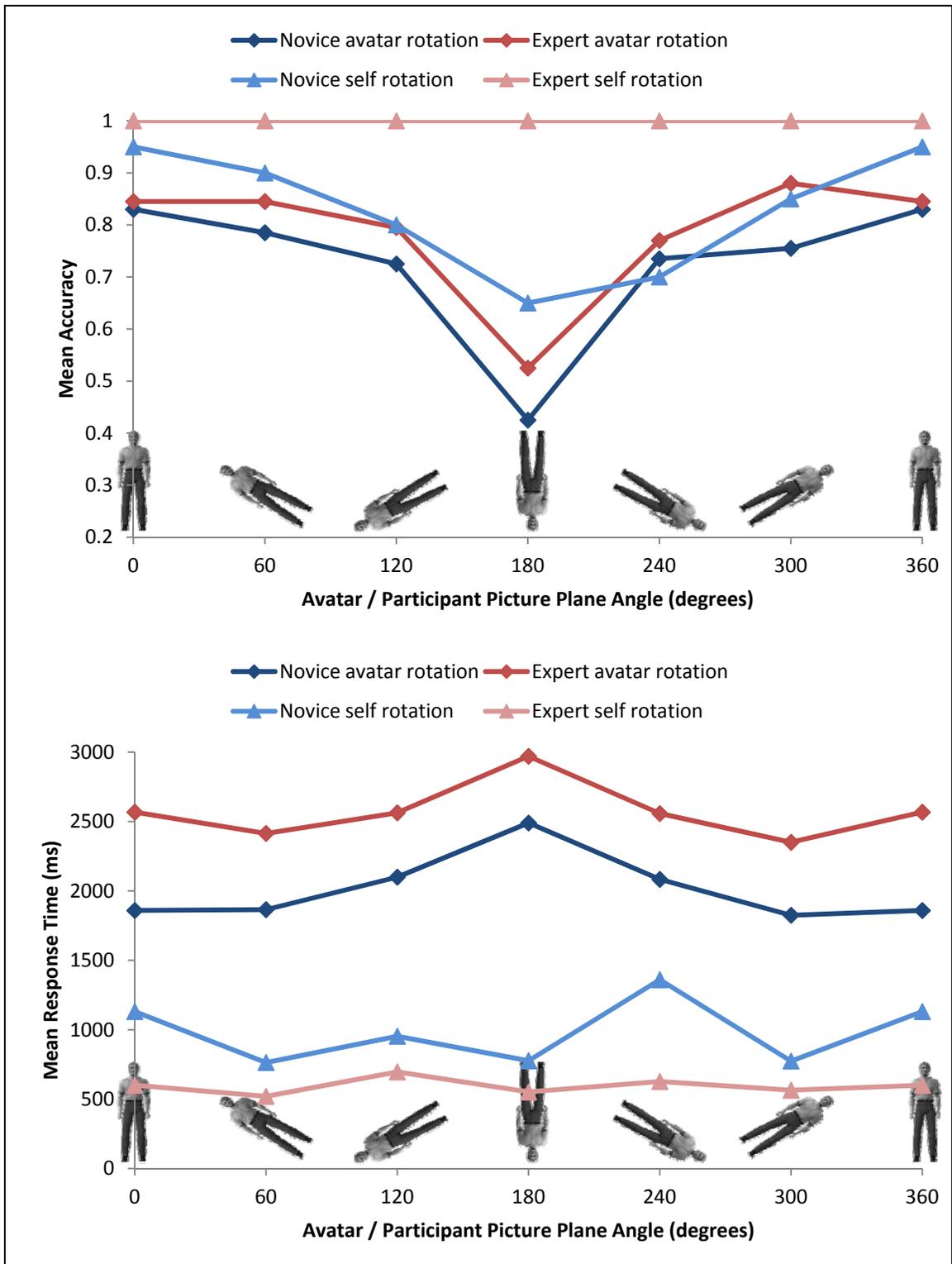


Figure 14. Mean accuracy and response times of both the expert and novice groups of Experiments 1 (perception of the avatar) and 4 (self perception).