CHANGE DETECTION OF A SCENE FOLLOWING VIEWER LOCOMOTION

CHANGE DETECTION OF A SCENE FOLLOWING A VIEWPOINT CHANGE: MECHANISMS FOR THE REDUCED PERFORMANCE COST WHEN THE VIEWPOINT CHANGE IS CAUSED BY VIEWER LOCOMOTION

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TITLE: Change Detection of a Scene Following a Viewpoint Change: Mechanisms for the Reduced Performance Cost when the Viewpoint Change is Caused by Viewer Locomotion

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Abstract

When an observer detects changes in a scene from a viewpoint that is different from the learned viewpoint, viewpoint change caused by observer's locomotion would lead to better recognition performance compared to a situation where the viewpoint change is caused by equivalent movement of the scene. While such benefit of observer locomotion could be caused by spatial updating through body-based information (Simons and Wang 1998), or knowledge of change of reference direction gained through locomotion (Mou et al, 2009). The effect of such reference direction information have been demonstrated through the effect of a visual cue (e.g., a chopstick) presented during the testing phase indicating the original learning viewpoint (Mou et al, 2009).

In the current study, we re-examined the mechanisms of such benefit of observer locomotion. Six experiments were performed using a similar change detection paradigm. Experiment 1 & 2 adopted the design as that in Mou et al. (2009). The results were inconsistent with the results from Mou et al (2009) in that even with the visual indicator, the performance (accuracy and response time) in the table rotation condition was still significantly worse than that in the observer locomotion condition. In Experiments 3-5, we compared performance in the normal walking condition with conditions where the body-based information may not be reliable (disorientation or walking over a long path). The results again showed a lack of benefit with the visual indicator. Experiment 6 introduced a more salient and intrinsic reference direction: coherent object orientations. Unlike the previous experiments, performance in the scene rotation condition was similar to that in the observer locomotion condition.

Overall we showed that the body-based information in observer locomotion may be the most prominent information. The knowledge of the reference direction could be useful but might only be effective in limited scenarios such as a scene with a dominant orientation.

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LIST OF ABBREVIATIONS AND SYMBOLS
In order of appearance

RT: Reaction time

SRC: Subject rotation with chopstick

TRC: Table rotation with chopstick

NRC: Nothing rotated with chopstick

BRC: Both (table and subject) rotated with chopstick

SR: Subject rotation without chopstick

TR: Table rotation without chopstick

LSRC: Long (310 degrees) subject rotation with chopstick

DSRC: Disoriented (spin) subject rotation with chopstick

DSR: Disoriented (spin) subject rotation without chopstick

LSR: Long (310 degrees) subject rotation without chopstick

NRI: Nothing rotated with intrinsic cue (objects at 0 degrees)

NRI-50: Nothing rotated with intrinsic cue (objects at 50 degrees)

TRI: Table rotation with intrinsic cue (objects at 0 degrees)

SRI: Subject rotation with intrinsic cue (objects at 0 degrees)

DECLARATION OF ACADEMIC ACHIEVEMENT

As this study was a collaborative effort, special consideration needs to be given to Melanie Iarocci for her work in Experiment 1, Keatha-Lee Robinson-Edwards for her work in Experiment 4, Hassan Sajid for his work in Experiment 5, and Daniel Zhou for his work in Experiment 6. As two experimenters were needed to run the experiments, we would run them together, or have an RA assisting one of us. The number of RAs who assisted us are mentioned individually in the Acknowledgements. We each did our own analyses and write-ups for our own respective projects.

General Introduction

We live in a world where our spatial environment is constantly changing. Nothing we encounter stays static in our visual field for long. We may see objects move in front of us across our retina. Even things that are stationary do not stay stationary in our retina for long due to movements of our body, head, or even eyes. Humans have evolved to recognize these changes in the spatial environment and to interpret whether these changes are due to movement in the environment or movement of the individual observer. This ability is also useful to determine what objects have been seen before and what objects are completely new to the observer. For instance, an observer may walk past a bench with individuals seated on it. The distance amongst the individuals remains the same as they have not moved, but to the moving observer, he or she will be viewing the scene from a different viewpoint and will be given a different image. In order to recognize that the scene has not changed, the observer may use information of the change in distance they have made, and recognize the difference between the scene they just saw and the scene seen before they moved. A similar situation occurs when an observer is waiting by a bus stop and sees a moving bus full of people drive by. In the moving bus, the distance amongst the seated passengers remain the same, but to the observer, the distance between the passengers and the observer are constantly changing as the bus drives by. The observer must take into account the fact that a feature of the environment, the bus, has moved, but that the passengers themselves have remained stationary, and that the changes in distance, from the bus coming to the bus going, is because of the bus moving, not each individual passenger moving independently. Thus it is not only important to recognize when a change in scene has occurred but also to recognize how the change in scene occurred, and whether the observer was part of the change (i.e. they moved in the environment), or whether they observed the change in scene without any involvement.

This ability to recognize our surroundings as well as our current position in the environment is referred to as spatial recognition. More specifically, spatial recognition allows us to take note of the distances between objects in a given environment, as well as to note the individual orientation of each object. Learning the layout of objects amongst other objects is known as object-to-object spatial relations. For example, in the bus scenario mentioned previously, recognizing how people are placed at the bus stop, and the distances and orientations of each individual with respect to every other individual, would be considered recognizing the object-to-object spatial relations in one's environment. Spatial recognition is also involved in self-to-object spatial relations, which is recognizing both in distance and orientation, where each individual object is in a given environment relative to the observer. In the bus scenario, recognizing where everyone on the bus is relative to the observer waiting would be considered recognizing the environment through self-to-object spatial relations.

There are two main frames of reference that people may use to encode and update their visual surroundings. The first one is an allocentric frame of reference, which is object-centered and utilizes object-to-object spatial relations. This means that observers using this frame of reference view the environment as if they are separate from it and merely encode and update the environment regarding where objects should be located relative to other objects after a given change in scene. For instance, if a given object is moved in the surroundings, the observer would take note of this change by observing the relations amongst the individual objects and recognizing which distances or relations are now different by recognizing which object had been moved. The object that was moved would have different relations amongst all the other objects in the environment.

In contrast, the egocentric frame of reference is viewer- or body-centered and utilizes self-to-object spatial relations. This means that observers using this perspective view the environment as if they are a part of the environment and encode and update the environment regarding where the observer is positioned and where the objects should be located in relation to the observer after a given change in scene. For instance, if a given object is moved in the surroundings, the observer would take note of this change by observing the relations amongst the individual objects relative to the observer and recognizing that the spatial relations are now different by recognizing which object had been moved. The object that was moved would have been positioned closer or farther away from the observer's perspective.

A number of researchers have proposed different models of how the two different frames of reference, egocentric and allocentric, are related and connected in spatial recognition (Burgess, 2006; Holmes & Sholl, 2005; Mou, McNamara, Rump, & Xiao, 2006; Mou, McNamara, Valiquette, & Rump, 2004; Waller & Hodgson, 2006; Wang & Spelke, 2000, 2002). There is some dispute about which frame of reference is the default when encoding a visual scene, although all models come to the conclusion that there is a switch in frame of reference when the default is deemed to have not enough fidelity or is not seen to be accurate enough to encode a scene. An egocentric frame of reference is seen to have higher fidelity, yet is limited, especially in time duration, and is available mostly through working memory. When a familiar environment is present, or there is a long duration of time, either for encoding or retention, an allocentric frame of reference appears to have higher fidelity, and is available in long term memory. Waller & Hodgson (2006) proposed their model as a two-system model, where the egocentric frame of reference is seen as being 'online' in the working memory and having higher precision in encoding scenes. When this frame of reference is no longer available, due to disruption in encoding or extended retention, the system goes 'offline' and resorts to using an allocentric frame of reference which has less precision but is enduring due to being stored in long term memory.

One of the popular paradigms in testing subjects' ability in spatial recognition is the change detection task. Numerous studies have employed this paradigm (e.g. Burgess, Spiers, & Paleologou, 2004; Finlay, Motes, & Kozhevnikov, 2007; Mou, Xiao, & McNamara, 2008; Mou, Zhang, & McNamara, 2009; Rieser, Garing, & Young, 1994; Simons & Wang, 1998; Wang & Simons, 1999). Studies utilizing this paradigm often involve observers learning an experimental environment for a brief period of time, at which point a change occurs without the observers' knowledge, e.g. an object is moved to a new location. After a specified retention period, the observers would look at the experimental environment again, and would have to point out or call out what the change was (i.e. what object moved). Some previous studies have displayed the object configurations on computer monitors and showed before and after pictures of a scene, although the majority of studies have used real objects in a real world environment, e.g. Mou et al. (2009) and Simons and Wang (1998) in particular, used real objects that were placed on a rotating platform, and usually only one object would be moved during the retention period. Adequate performance in the change detection task has been found in subjects as young as 8 years old (Rieser et al., 1994), so experiments using this paradigm often yield robust data.

When a change in the spatial environment has occurred in change detection tasks, a viewpoint shift can also occur. A viewpoint shift is the change in viewpoint from the observer's perspective, from the start of a trial to the end. A familiar viewpoint is seen when no movement is involved (except for the object in question) or when both observer and scene have moved together. For example, if using a rotated table, both the table and the observer could move together, so that the observer would be presented with the same viewpoint, since the table and observer would be aligned, although in a new location relative to the environment. A novel viewpoint is seen when only the observer or the scene (e.g., the table) has moved. A change in only one of these aspects would result in a novel viewpoint, as the observer would be presented with a viewpoint where he or she (the observer) and the scene would no longer be aligned with where they were at the start of a trial.

When taking into account viewpoint shifts in the change detection task, researchers have looked into how spatial recognition performance is affected by these shifts and whether observers' performance is viewpoint-independent or viewpoint-dependent (e.g. Biederman & Gerhardstein, 1993; Burgess, 2006, 2008; Christou & Bülthoff, 1999; Finlay et al., 2007; Greenauer & Waller, 2008; Mou, Liu, & McNamara, 2009; Mou et al., 2006; Mou, Xiao, et al., 2008; Mou, Biocca, et al., 2004; Roskos-Ewoldsen, McNamara, & Shelton, 1998; Shelton & McNamara, 2001; Sholl, 1999; Simons, Wang, & Roddenberry, 2002; Sun, Chan, & Campos, 2004; Tarr & Bulthoff, 1995; Wang & Simons, 1999; Wang & Spelke, 2002). If observers encode a layout in a viewpoint-independent manner, then they ought to be able to recognize the layout from any other viewpoint. In other words, they have encoded the layout that is independent of how they viewed the layout from their original, starting viewpoint. No matter where they move to, observers should be able to recall the layout they have memorized and apply it to the current viewpoint of the layout, and thus extrapolate what changes have been made in comparison to natural rotations of the scene. Regardless of whether observers are presented with a familiar or novel viewpoint, spatial recognition performance should be comparable between the two. However, if observers encode a layout in a viewpoint-dependent manner, then they ought to have increasing difficulty in spatial recognition the farther away their current viewpoint is from their original viewpoint. In this case, they have encoded a layout in a manner that is dependent on how it was seen from their original, starting viewpoint, and thus have weaker performance the more dissimilar (more rotated) their current viewpoint is from the original viewpoint. Thus a greater degree in shift from the original to the new viewpoint leads to poorer spatial recognition.

It is clear that encoding our environment in a viewpoint-independent manner is ideal in order to generalize to new viewpoints, however it is more difficult to construct such a representation, compared to encoding in a viewpoint-dependent manner. As described in the studies mentioned above (Biederman & Gerhardstein, 1993; Burgess, 2006, 2008; Christou & Bülthoff, 1999; Finlay et al., 2007; Greenauer & Waller, 2008; Mou, Liu, et al., 2009; Mou et al., 2006; Mou, Xiao, et al., 2008; Mou, Biocca, et al., 2004; Roskos-Ewoldsen et al., 1998; Shelton & McNamara, 2001; Sholl, 1999; Simons et al., 2002; Sun, Chan, et al., 2004; Tarr & Bulthoff, 1995; Wang & Simons, 1999; Wang & Spelke, 2002), to generate a viewpoint-independent representation, more time is needed for the observers to learn the layout. In familiar environments, observers have a clear image of the layout in their head that can be easily rotated to any viewpoint. However, most studies (including the current study) only offer an experimental environment that is completely novel to the observers. Some of the mentioned studies (Diwadkar & McNamara, 1997; Roskos-Ewoldsen et al., 1998) have pointed out that simply allowing observers to view a layout from multiple viewpoints at the start does not necessarily lead to viewpoint-independence, but rather, could generate multiple viewpoint-dependent perspectives. Viewpoint-independence is more likely to occur if observers are able to move around and interact with the environment (Sun, Chan, et al., 2004), thus becoming more familiar with it.

When taking into account only the retinal image of the spatial environment, no matter where the scene or observer has moved, as long as both move together, the observer will have the same viewpoint projected onto his or her retina. Likewise, regardless, for example, whether the observer has rotated 50 degrees away from the start, or the scene has been rotated 50 degrees away from the start, the observer is being presented with a novel viewpoint where there is a 50 degree shift between the observer and the scene.

Benefit of spatial updating via body-based information

It has been repeatedly shown that a novel viewpoint shift incurs a cost to accuracy, especially as the shift between observer and scene increases, away from the original viewpoint acquired. However, different results have been observed depending on what was moved to achieve the given viewpoint shift. Simons and Wang (1998;) see also Simons, Wang, & Roddenberry, 2002; Wang & Simons, 1999) have demonstrated this exact point. They used the change detection paradigm. During test, half of their subjects remained in the original unchanged study position, while the other half moved to a chair 47 degrees away. For all subjects, half of the trials involved rotating the table 47 degrees and on the other half of the trials the table remained stationary. The subject was then asked to identify which object moved. Simons and Wang (1998) had originally hypothesized that if visual information is the only cue that subjects use, then performance for both familiar viewpoint conditions should be equal, and thus object recognition should remain unaffected. As well, accuracy levels for novel viewpoints should be roughly equal whether the table or the observer moved, as the scene being shown is the same for both conditions. Unlike what was predicted by the purely “visual” hypothesis, subjects in the unchanged position group were significantly more accurate in the familiar viewpoint condition (table stationary-observer stationary) than that of the subjects in the changed position group (table rotation-observer locomotion). As well, subjects in the changed position group were significantly more accurate in the novel viewpoint condition (table stationary-observer locomotion) than that of the subjects in the unchanged position group (table rotation-observer stationary).

Simons and Wang (1998) concluded that observers may have represented the relation between the object array and their own position in a viewer-centered (egocentric) frame of reference, and the representation would have been updated by proprioceptive ('extra-retinal') information, or body-based cues, to account for observer locomotion. Had an allocentric frame of reference been used, there should have been no difference in the novel viewpoint conditions. The body-based mechanism does not depend on visual information to accommodate the change in observer position, but instead can use body-based and vestibular information exclusively without vision. Hence, what is important here is that observers are able to spatially update their surroundings not through vision or imagination, but by having a 'feel' of where they are moving around the environment. By sensing how much they have moved or rotated around a scene, they can estimate before viewing the scene again, what the environmental layout should look like based on their current displacement from the observers' original viewpoint. The benefit from the body-based cues gained from this procedure cannot be found when the scene rotates as it is moving independently of the observer's body. Therefore, view changes caused by the rotating table should lead to higher errors than those caused by observer locomotion. The viewpoint change caused by the observers' locomotion produced a minimal cost in recognition performance due to updating the spatial representations during movement and the proprioceptive feedback.

Even though subjects were encoding from an egocentric frame of reference, the minimal cost found in the observer locomotion conditions, demonstrate that subjects were at the same time processing the scene in a more viewpoint-independent manner. This can account for the results found by Simons & Wang (1998), as the main disruption in performance was the shifting of the table, not the subject. Thus observer locomotion has a facilitative effect on spatial recognition performance.

The effects of body-based cues (or the effects of observer locomotion) on spatial recognition have been demonstrated in other similar studies. Some studies (Christou & Bülthoff, 1999; Coluccia, Bosco, & Brandimonte, 2007; Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Simons et al., 2002; Sun, Campos, Young, Chan, & Ellard, 2004; Sun, Chan, et al., 2004; Wang & Simons, 1999; Wraga, Creem-Regehr, & Proffitt, 2004; Yardley & Higgins, 1998) have directly compared the use of active and passive movement to investigate how active the observer must be to make use of the same facilitative benefit from body-based cues. Active movement would involve the observer actually moving around the environment him or herself, regardless of whether blindfolded or not (vision does not matter in this case). Passive movement could involve a number of things such as the observer being moved by the experimenter, e.g. in a wheelchair, viewing someone else move along the environment (dynamic), or even viewing photographs of the experimental layout had the observer been moved to the pictured viewpoint (static). There is some debate about whether active and passive movement yield the same results, and whether passive movement can still utilize body-based cues. For instance Christou & Bülthoff (1999) found no difference between active and passive observers (who saw someone else moving), but did find passive observers' ability to accommodate rotations was limited to short distances. On the other hand, Klatzky et al. (1998), using a similar procedure, found that passive observers had more difficulty performing than active observers who actually moved; they suggested that passive observers' greater difficulty was because they still had to imagine that they were doing the movement after viewing someone else. These studies suggest that in order for passive movement to cause equivalent effects to active movement regarding the use of body-based cues and spatial recognition performance, then observers must at least have the sense of being moved, like being pushed in a wheelchair (i.e. Wang & Simons, 1999). In this way, observers can still utilize body-based cues by being moved. For example, Sun et al. (2004) found that subjects who operated a computer mouse yielded similar spatial recognition results as subjects who were active by peddling a bike. Both were able to utilize body-based cues but the former situation was done in a virtual environment rather than a real one. This suggests that minimal proprioception is sufficient for incorporating body-based cues into spatial recognition. Seeing static images of a new viewpoint appears to have no effect, as observers are not going through any movement, nor are they observing it as a bystander, thus they have no sense of body-based cues in this case. In a follow-up to the study by Simons and Wang (1998) Simons et al. (2002) replaced active movement with static images. In one experiment, the trials were static as there was no movement from either the subjects or the table. Instead, subjects were tested based on photographs given to them showing what the scene would look like had they moved or had the table moved. No difference was found between the novel viewpoint conditions, thus the differences amongst the conditions were based on actual movement, especially when subjects received body-based cues when they moved. To see if there was an active vs. passive movement effect on scene rotation, Wang and Simons (1999) also compared subjects who actively rotated the scene to those who had the experimenter do it, but there was no difference, meaning active control of a scene made no difference, likely due to the fact that proprioception information was not involved in either case.

Path integration, an important ability requiring active movement, involves updating one's current position or displacement from the starting point, by integrating one's movement experienced along a path's trajectory (Berthoz, Israel, Georges-Francois, Grasso, & Tsuzuku, 1995; Burgess, 2008; Campos, Byrne, & Sun, 2010; Gibson, 1950; Holmes & Sholl, 2005; Kelly, McNamara, Bodenheimer, Carr, & Rieser, 2008; Klatzky et al., 1998; Mittelstaedt & Mittelstaedt, 1980; Mou et al., 2006; Sun, Campos, & Chan, 2004; Sun, Lee, Campos, Chan, & Zhang, 2003; Wang & Spelke, 2000, 2002; Zhang, Zhang, & Wang, 2013). Observers moving along their environment can estimate where they are by incorporating their sense of self-movement into their estimate of the distance between their old and new positions or their change in viewpoint with respect to the origin. This mechanism is not possible to engage by a stationary observer when faced with a rotated scene, even if the observer actively rotated the scene (Wang & Simons, 1999), due to the lack of self-motion signals. To A study conducted by Berthoz et al. (1995) illustrates the importance of path integration. They tested subjects in robotic cars that they could control. Subjects were blindfolded during both learning/practice and test phases, and had to travel the same distance during the test phase that they travelled in the learning phase, with only the use of vestibular information they received during practice. Not only did subjects try to reach the same distance but they would do so by traveling at the same velocity they did at the practice trials. Subjects were trying to recreate what they experienced during practice trials and were doing so through the use of vestibular signals which allowed for real-time updating of their body in space and time. Thus movement was being stored as something dynamic rather than as something static (remembering the distance it took to get to the endpoint, without incorporating velocity).

The effect of body-based information is prominent in numerous studies involving pointing to objects in both moving and imagining tasks (Burgess, 2006, 2008; de Vega & Rodrigo, 2001; Farrell & Robertson, 1998; Greenauer & Waller, 2008; Huttenlocher & Presson, 1973, 1979; Klatzky et al., 1998; May, 2004; Mou, Li, & McNamara, 2008; Presson & Montello, 1994; Rieser, Guth, & Hill, 1986; Rieser et al., 1994; Rieser, 1989; Shepard & Hurwitz, 1984; Simons et al., 2002; Wang & Simons, 1999; Wraga et al., 2004). In the studies of learning room size environment, subjects would typically be tested in a room with objects placed on all sides of the room. Subjects would study the objects and would then be given practice by closing their eyes and pointing to a cued object. During the actual experiment, in the rotation conditions, subjects would be actually rotated or had to imagine a rotation. When subjects actually had to rotate to a new viewpoint and then point to an object, there were fewer errors relative to imagined rotation, as proprioceptive information was available from moving, which was caused by spatial updating of the environment in an automatic manner. When subjects had to imagine they had rotated and had to point to an object from the imagined viewpoint, there were more errors as subjects were not able to get a sense of where their new position would be in the same way had they actually moved and received proprioceptive or body-based feedback. There was a conflict between one's current viewpoint in the environment and the imagined viewpoint. Subjects have difficulty pointing accurately to an object from an imagined viewpoint when their body-based information is telling them no movement was involved. This is another reason why observer locomotion is advantageous as it permits one to utilize body-based information, whereas in imagination situations, conflict arises as body-based information must be ignored in order to be able to imagine being in a different viewpoint. This parallels the reason why observer locomotion yields greater performance in spatial recognition than scene rotation, as when the scene rotates, but not the observer, the observer has to contend with the fact that a viewpoint shift has occurred without any movement (on the observer's part) and must perform the task by also ignoring his or her body-based information (telling him or her no movement has occurred and therefore no viewpoint shift should have occurred).

An alternative view to body-based spatial updating

Studies such as that by Mou et al. (2009) offered a different perspective that challenged the notion that body-based information was the reason why observers had better performance during observer locomotion compared to scene rotation. Their model suggests that during learning, observers take a small number of reference directions and that observer movement allows subjects to easily update spatial memory based on these reference directions. Specifically, when learning a spatial layout, an observer must first establish a direction of where they are in that space and after a change in viewpoint; the observer must now try to locate the direction they are facing relative to the previous direction before the viewpoint shift. Having the knowledge of where one moves to, one can then better find where they are in the spatial layout. While Simons and Wang (1998) among others, concluded that observers updated their spatial memory through movement, Mou et al. (2009) claimed that movement is unnecessary and that movement merely generates knowledge that can be used to find the direction of a new location. Any direction cue can be just as good as, if not better than, body-based information, in finding the direction of a viewpoint shift, and therefore an observer does not need to move to acquire this knowledge. Therefore having a cue that signifies reference direction can replace the knowledge gained through path integration from observer locomotion. What this also means is that both novel viewpoints, observer locomotion and scene locomotion, can yield comparable results, if directional information is available. In their study, Mou et al. (2009) first conducted a replication of Simons and Wang (1998) and then several follow-ups to provide an alternate explanation to the results discovered by Simons and Wang (1998).

Mou et al. (2009) showed that when a reference direction cue was introduced, the difference between the subjects' locomotion and scene rotation conditions disappeared. Specifically, indicating the study view (origin) through a chopstick on the table at the test view (new viewpoint) facilitated change detection at least as well as locomotion, and both conditions produced equally accurate spatial reference directions. Mou et al. (2009) suggested that when an observer's locomotion is involved, there is higher accuracy due to the update of a reference direction through the knowledge of the movement. When additional reference direction cues were present, even without the observer's locomotion, performance in the novel viewpoint conditions were comparable with each other. In their study, the use of the chopstick as a spatial reference direction cue in the test phase provided information about the reference direction which, they argued, serves the same purpose as that of the proprioceptive feedback gained in the table stationary-observer locomotion condition.

A reference direction can be obtained from an external cue, such as Mou et al.'s (2009) chopstick, but it can also be obtained from the internal configuration of the environment. Many studies have demonstrated that high performance in spatial recognition tasks is largely due to the intrinsic reference system present in one's surroundings (Burgess, 2006, 2008; Greenauer & Waller, 2008; Holmes & Sholl, 2005; Kelly & McNamara, 2008; Mou, Liu, et al., 2009; Mou et al., 2006; Mou, McNamara, et al., 2004; Mou & McNamara, 2002; Mou, Xiao, et al., 2008; Shelton & McNamara, 2001; Vidal, Lehmann, & Bülthoff, 2009; Wraga et al., 2004). An intrinsic reference system consists of salient axes and planes that are found in the configuration of object layouts. For instance, a row of objects is situated on an intrinsic axis if they are aligned and placed in a straight line on a table. These studies suggested that subjects utilized allocentric processing on the spatial recognition tasks as opposed to the traditional egocentric processing. The layout of objects along a salient axis would have provided a reference direction, and during processing, this linear spatial relation between the objects would have allowed them to be grouped into a cluster. When movement is involved, subjects should be able to retain the configuration of these clusters of objects. While cues outside of the scene, such as any features along the walls of the experimental room, have little effect on performance, the layout of the objects along salient axes or planes can improve spatial memory. Thus, as long as an intrinsic reference frame is available in the environment, high performance in spatial recognition can be obtained regardless of observer or scene locomotion.

Studies have looked into how performance in spatial recognition tasks can be improved when a novel viewpoint is aligned with environmental landmarks (Burgess et al., 2004; Burgess, 2006, 2008; Byrne, Becker, & Burgess, 2007; Coluccia et al., 2007; de Vega & Rodrigo, 2001; Holmes & Sholl, 2005; Mou, Liu, et al., 2009; Mou et al., 2006; Shelton & McNamara, 2001; Sholl, 1999; Sun, Chan, et al., 2004; Wang & Spelke, 2000, 2002; Zhang et al., 2013). Thus object locations relative to environmental cues were tested. For instance, Burgess et al. (2004) did a study where the setup of the experiments was similar to that of Simons and Wang (1998), except a cue-card was used as a cue and for half of the trials involved, the cue-card was moved independently of the table. Except for the control conditions (with and without the cue-card moving) the observer locomotion condition had the highest performance, however, the cue-card when added to trials involving table rotation, and the rotation of both subject and table, increased performance. There was no effect when the cue-card was added solely to the subject locomotion trials. In this study, all objects would have been relative to this one external cue (the cue-card) within processing spatial memory. Based on the results, it is clear the cue-card landmark was encoded as part of the scene, such that performance was only affected when the cue-card moved with the table. Other conditions had no effects; subjects could have been perplexed by seeing only part of the scene move (the table only or the cue-card only). Thus landmarks can serve as cues for an intrinsic reference frame as long as they are encoded with the rest of the scene. This would explain why environmental feature cues, such as features along the walls of the testing room, have shown to have no effect on performance, as they have not been encoded by subjects as being part of the object layout. The results of these studies point out the strong influence of alignment effects (i.e. Farrell & Robertson, 1998; Roskos-Ewoldsen et al., 1998; Sholl, 1999). Alignment effects refer to spatial recognition performance being dependent on the observer's original viewpoint, and how far the new viewpoint is from the original viewpoint. When observers are able to move in their environment, they are able to spatially update their position automatically, thus alignment effects are not a concern. However, the same cannot be said for conditions where the scene rotates or observers must imagine being in a different rotation. There is no automatic updating process in these cases. Thus, the farther away the new viewpoint (real or imagined) is from the original, the greater the detriment on spatial recognition performance. Intrinsic reference frames can decrease alignment effects. As seen in the Burgess et al. (2004) study, performance was improved only when the landmark cue was aligned with the scene. Thus by having a landmark aligned with the rotating scene, there is less of a dependence on the observers' original viewpoint. Likewise, by having objects clustered along salient, intrinsic axes, there is less dependence on original viewpoint. Observers can encode the objects relative to these axes compared to their egocentric viewpoint, and when the scene moves, for instance, as long as these axes can be recognized by observers, alignment effects (on observer viewpoint) will decrease as will the cost of viewpoint shift.

Along with landmarks, instructional cues can also provide enough information for observers to perform spatial recognition tasks (Greenauer & Waller, 2008; Holmes & Sholl, 2005; Mou, Li, et al., 2008; Mou, Liu, et al., 2009; Mou & McNamara, 2002; Mou, Biocca, et al., 2004; Roskos-Ewoldsen et al., 1998; Sholl, 1999). Greenauer and Waller (2008), for instance, concluded that physical intrinsic structures for organizing spatial memory are not necessary (though can be beneficial) for utilizing an allocentric (or nonegocentric) frame of reference. If detailed instructions are given to subjects, telling them exactly how they can process a scene and increase performance in spatial recognition tasks, then the instructions can guide subjects how to learn the layout of objects from an allocentric viewpoint. Without these detailed and informative instructions, subjects may resort back to egocentric processing. Thus subjects can perform better in scene memory tasks involving locomotion if they receive instructions on how to optimize their spatial processing. In essence, guided instructions on how to study a layout replaces physical intrinsic axes with mental intrinsic axes, leading subjects to encode a scene based on an organized, allocentric configuration.

Studies involving disorientation have shown that benefits gained from observer locomotion can be quickly lost, and that in order to achieve accurate spatial recognition performance, observers must adapt to encoding the scene allocentrically (Burgess, 2006; Holmes & Sholl, 2005; Kelly et al., 2008; Kelly, McNamara, Bodenheimer, Carr, & Rieser, 2009; Mou et al., 2006; Mou, Xiao, et al., 2008; Roskos-Ewoldsen et al., 1998; Waller & Hodgson, 2006; Wang & Spelke, 2000, 2002; Yardley & Higgins, 1998). Subjects who were disoriented before being placed in a new viewpoint were unable to automatically update their current position from their original position. Thus the updating procedure encompassing path integration is disrupted and is no longer useful. If subjects encode the scene allocentrically, disorientation will have less of an effect. If a landmark is present or any intrinsic axis is recognized, subjects can reorient themselves and refer to the memorized layout, thus preventing a deficit in performance. It should be noted that disorientation had no effect in familiar environments. This is likely due to the fact that subjects had a ‘cognitive map’ (Tolman, 1948) retained in their memory.

To summarize, Simons and Wang (1998) and Mou et al. (2009), have found that there is a reduced cost of viewpoint shift when observers moved compared to the case where the table rotated. A major component of Simons and Wang’s (1998) paradigm is the effects of proprioceptive information on spatial layout recognition, whereby observers update their spatial representations to accommodate the changes in their body position and orientation. However, Mou et al. (2009) have come to the conclusion that performance depends on what reference direction information is available. For example, the observer locomotion condition uses proprioceptive information from movement, whereas the table rotation condition has no such source of information. When a visual cue (chopstick) indicating the learned (original) viewpoint is added, there is an increase in performance even without observer movement, thus the table rotation condition can be just as accurate, if not more accurate than the observer locomotion condition. The current study will address this debate.

Current Study

The current study involves six experiments. Experiment 1 was performed as a replication of Experiment 3 of Mou et al. (2009) involving two familiar (no movement, both movement) viewpoint conditions and two novel (observer movement, table movement) viewpoint conditions.

A visual indicator was included in the test phase. Experiment 2 focused on the effect of the visual indicator (by comparing the performance with and without the visual indicator for the two novel viewpoint conditions. Experiment 3 was done to test, with the presence of a visual indicator, whether performance in conditions where body-based information was disrupted (disorientation condition) or unreliable (condition involving walking over a long path) would be comparable to that of the normal locomotion condition. Experiments 4-5 concentrated on the effect of disorientation and indirect walking respectively, and compared the presence vs. the absence of the visual indicator. This would test to see after having body-based information disrupted, whether or not subjects would utilize the visual indicator as a cue of reference direction (if provided). Experiment 6 replaced the visual indicator with a more salient and intrinsic reference direction, object alignment. Instead of being placed in random orientations, all objects were placed in the same orientation (facing the same direction). This was to test whether having an intrinsic cue instead of an external landmark was more effective in bringing about equivalent performance in the two novel viewpoint conditions (table rotation vs. subject locomotion).

Experiment 1

Simons and Wang (1998) and Mou et al. (2009) offered different explanations regarding mechanisms of spatial updating that occur with locomotion, and in particular the role of body-based cues in spatial recognition. It is our main goal to address this debate and to determine whether locomotion contributes more than merely providing information about reference direction. To first address this debate and provide a foundation for the study, Experiment 1 was performed to replicate Mou et al.'s (2009) third experiment, as we wanted to ensure the effect of the visual indicator indeed existed. As in Mou et al. (2009), there were four conditions in the experiment. Two of the conditions involved a familiar viewpoint in that during test, subjects were shown a layout that was identical to the previous layout shown. In these familiar viewpoint conditions, either both observer and scene remained stationary, or both were moved in the same direction and magnitude. The other two conditions involved a novel viewpoint in that subjects were shown a layout that was shifted from its original layout. The two conditions involved the movement of the scene or observer. A chopstick was used as a visual reference direction cue during the testing phase. This visual cue pointed to the origin or starting position of where an observer was at the start of a trial. It also gave an indication of reference direction in that it provided the observer information about the extent of travel during the testing phase.

With the presence of the visual indicator, if performance in the novel viewpoint condition involving observer locomotion is still superior (greater accuracy and faster reaction time) than in the novel view condition involving scene rotation, then the results would be consistent with the view proposed by Simons and Wang (1998). Based on their findings, the observer locomotion condition should have better performance because observers have the advantage of utilizing body-based cues. The observers' locomotion could provide efficient proprioceptive information informing them about the distance travelled, something that is not found in the scene rotation condition. In fact in the scene rotation condition, there is conflict between the body-based cues (no movement of observer) and the scene shifting. Due to this conflict, based on Simons and Wang (1998), performance would be hindered, regardless of the presence of a visual indicator, which would prove to have no benefit.

However, if the visual indicator is effective as a reference direction cue, then performance of both novel conditions should be comparable, thus bringing validation to Mou et al.'s (2009) argument. Based on their findings, observers may receive information through locomotion and/ or through the chopstick which acts as an alternative cue to reference direction. Since both conditions now have a source of reference direction (observer locomotion or visual indicator), performance should be comparable in both.

Methods

Experiment 1 was essentially the same in design as Mou et al. (2009) with a few differences in methods. Most notably, this experiment was within-subjects, rather than between-subjects as in both Simons and Wang (1998) and Mou et al. (2009). We were also the first among the studies using the same paradigms to collect reaction time (RT) data in addition to accuracy.

Subjects

Twenty-seven subjects (10 males, 17 females), all undergraduate students from McMaster University, ranging from 17 to 27 years of age (M = 18.71, SD = 1.86), participated in the experiment for two course credits.

Materials and Design

The testing area was a large, round, enclosed area consisting of wooden beams acting as a frame that supported a metal ring close to the ceiling. Draped along the ring, covering the beams, was opaque black fabric which formed walls. The ceiling was also covered with the fabric. An entrance was simply a slit in the fabric between two beams. During the experiment, the lights were off at all times such that the external environment was completely invisible. With the lights off and the structure forming a perfect circle, subjects could not distinguish any corners or edges of the room. In the centre of the room there was a white, circular, rotating table (1.2 m diameter; 0.75 m from the ground). The experimental display consisted of five real, unique objects, those being a stapler, brush, scissors, tape dispenser, and glasses. Around the table, on the floor, were black tape markings at equal intervals of 10 degrees. This was used by the experimenter to rotate the table, or to move subjects around the table, an exact amount.

MATLAB 7.0 was used to generate 64 (4 practice and 60 test) irregular spatial configurations of the five objects. Of the five spots generated randomly by the program, each was designated a different letter ranging from A-E which was associated with a given object. Each object was associated with the given letter at all times during the experiment. For instance, the brush was associated with the letter B, and for every trial the brush would be placed on the spot designated with 'B'. The computer program randomly selected which object to be moved, and dictated the direction of movement. Movement of the objects was always of the same magnitude (approximately 15 cm). In order to ensure accurate and timely control by the experimenter, a projector was attached to the ceiling directly above the table. This projector presented the configurations and the alterations made to the layouts. The beam of light from the projector enabled subjects to see the spatial arrangement of objects on the table, but nothing else, so subjects only saw a dimly lit table with the five objects arranged.

This experiment involved two experimenters. The primary experimenter ran subjects throughout the experiment. This experimenter made the necessary changes on the scene and guided the subjects' movement if needed. The secondary experimenter, known as the operator, was in charge of the computer program, and initiated trials as well as recording subjects' responses in the program. The operator was unseen by the subjects as he or she was located outside of the enclosed experimental area.

Procedure

After signing a consent form, subjects were brought into the lab blindfolded and led by the experimenter, and the lights were kept off. Subjects remained standing throughout the experiment and they wore headphones playing white noise throughout all the trials to minimize any auditory localization cues. This was also done especially to avoid having subjects acquire any sounds from the movement of the designated object. The subjects remained blindfolded except during the learning and test phases, in order to avoid seeing the changes occurring in the spatial scene. The experimenter wore cordless headphones to receive computer instructions. In order to communicate, the experimenter tapped the subject on the shoulder signaling to place their blindfold back on or to take it off. At the start of the experiment, the experimenter provided instructions to the subjects. The subjects were told of the four different conditions that would occur throughout the experiment, and were given a practice trial for each condition at the very start of the experiment (4 in total). Subjects were not notified of what condition would be run at the start of a trial. As the same magnitude and direction were used throughout the experiment, the subjects were told that any movement of themselves and/or the table would always be 50 degrees to the right. Subjects were also informed that a visual indicator (chopstick) would be present during the test phase and told that it indicated their position in the learning phase.

During the learning phase, subjects stood at the learning position designated at 0 degrees around the table. The projected image at the start of every trial informed the experimenter where to place the objects and whether the subject and/or table needed to be moved 50 degrees. Following the practice trials, blocks of five trials involving the same condition were presented in sequence; otherwise the order of conditions within a block was randomized. At the start of a trial, once the experimenter finished placing the five objects to their indicated spot, the experimenter called out “Go” for the operator outside to start the trial, at which point upon hearing the trial start, the experimenter tapped the subject to lift up their blindfold. Subjects only had five seconds to learn the layout of the objects at which point they were then tapped on the shoulder to place their blindfold back on.

The retention phase consisted of a 17 second interval where the experimenter first moved one of the objects (as indicated by the image projected onto the table by the projector). The experimenter had approximately five seconds (of the 17) to do this before the projection changed. A chopstick was placed in the center of the table during the retention phase pointing to the subjects, and the appropriate movements were then initiated (movement was 50 degrees to the right, done to the subject and/or the table). Thus if the table was rotated, the chopstick was rotated as well, since it would always point to the viewpoint where the subject learned the layout of the objects. The experimenter knew how far to rotate the table as the projector projected an image where the location of each object was shifted 50 degrees to the right. The experimenter just had to rotate the table until the objects matched with the appropriate location indicators. If no table rotation was involved, the projected image would remain the same. If subject's movement was involved, the experimenter gently guided subjects by the shoulder to get the subjects to shuffle along towards the 50 degree mark.

Once the experimenter received notification that the retention phase was finished, he or she then tapped the shoulder of the subjects who then lifted their blindfold off and called out which object they thought moved during the test phase. The projector just dimly lit the table with the objects. The operator, located outside of the enclosed area and situated at a computer, recorded the subjects' response and then proceeded to the next trial once the experimenter was ready for the next trial. At the end of the experiment, subjects were debriefed, and received their credit.

All subjects went through four conditions, which were: subject rotation/table stationary with a novel viewpoint (SRC), table rotation/subject stationary with a novel viewpoint (TRC), table/subject stationary with a familiar viewpoint (nothing moved) (NRC), and table and subject rotation with a familiar viewpoint (both table and subject moved to the same extent) (BRC) (see Table 1 and Figure 1 for layout of conditions). Condition 3 acted as a control condition since no movement was involved, therefore it served as a baseline for subjects' performance in remembering and detecting change. There were two sessions performed on two different days for each subject, with 64 trials per session. Each subject went through 30 trials per condition in total.

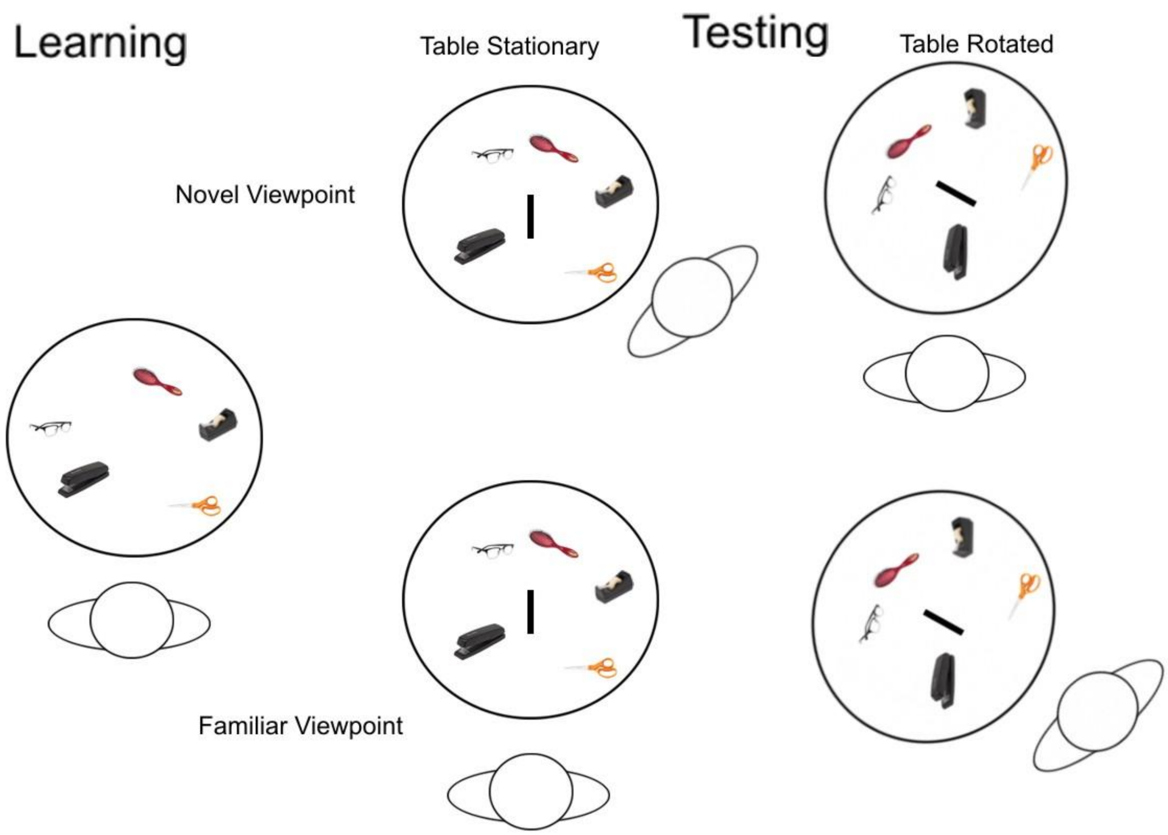

Figure 1 – Experiment 1 Conditions

Table 1 - Experiment 1 Conditions

Condition	Table at test	Observer at test	Presence of chopstick
SRC	0	50 walk	During test
TRC	50 rotation	0	During test
NRC	0	0	During test
BRC	50 rotation	50 walk	During test

Results

Five subjects were removed in the final analysis. One subject did not show up for the second session, two performed below 50% accuracy in the control condition (NRC), and two performed below 30% accuracy overall in all trials. Any trials with a reaction time below 1 second and above 25 seconds were also removed.

For accuracy, the results of paired, one-tailed t-tests were significant when we compared the two novel view conditions (SRC and TRC) [$t(21) = 2.52$, $p < 0.01$)], and the two table stationary conditions (SRC and NRC) [$t(21) = 6.55$, $p < 0.001$)] (see Figure 2). For RT, the results of paired, one-tailed t-tests for correct trials were also significant when we compared the two novel viewpoint conditions (SRC and TRC) [$t(21) = 6.11$, $p < 0.001$)], and the two table stationary conditions (SRC and NRC) [$t(21) = 3.31$, $p < 0.01$] (see Figure 3). These accuracy and RT results both suggest that the visual indicator did not improve the performance of the table rotation condition to the extent that matched the level of the subject rotation condition, and in addition, even with subject locomotion, there were still costs of viewpoint change compared to the control.

Discussion

When considering the novel viewpoint conditions (SRC and TRC), among the two hypotheses mentioned earlier, we found clear evidence supporting Simons and Wang's (1998) claim. Simons and Wang (1998) proposed that increased performance in a change detection task was due to body-based cues, regardless of additional cues presented. In contrast, Mou et al.

(2009) suggested that performance across conditions could become comparable as long as a proper reference direction cue was present throughout. Whereas subjects had locomotion to assist them in the subject rotation condition, equal performance could be obtained in the table rotation condition with the visual indicator present.

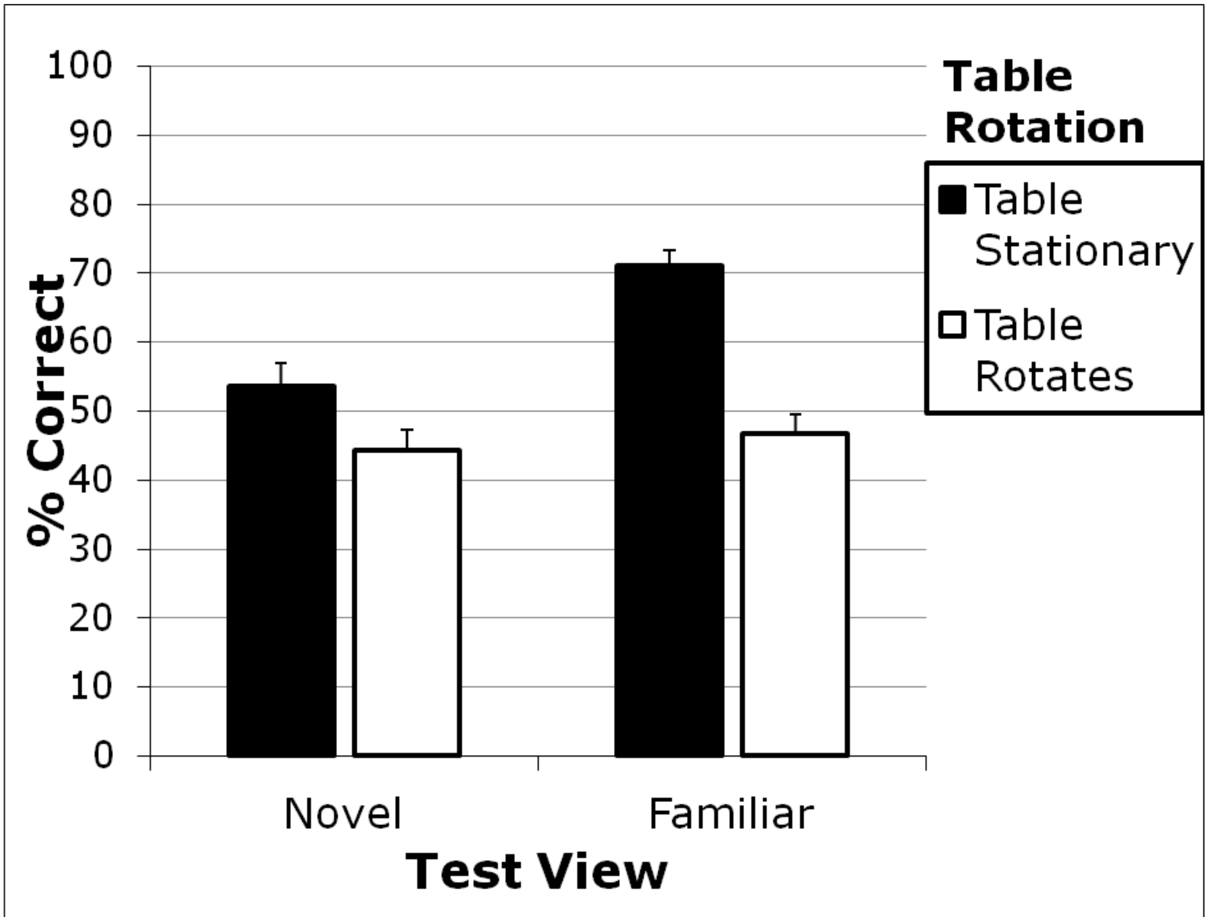

Figure 2 – Accuracy in detecting position change as the function of table rotation and test view

In our study, in the novel viewpoint conditions, subjects performed better (greater accuracy and lower reaction time) when they moved compared to when the table rotated. In contrast to the findings of Mou et al (2009), the visual indicator as a reference direction cue did not eliminate the difference between these two conditions, as there was a significant difference found in both accuracy and reaction time between the two conditions. We can conclude that there was a greater benefit to be found in spatial recognition performance when body based cues were used compared to visual reference direction cues. It is important to point out that we used a within-subjects design and showed significantly higher cost in the table rotation condition than that in the subject rotation condition. In contrast Mou et al (2009) used a between-subjects design and showed a comparable performance for the table rotation and subject rotation conditions, which could be caused by better performance in the table rotation condition and/or worse performance in the subject rotation condition in two groups of subjects and two different tests. As found in Mou et al. (2009), participants still performed the greatest in the familiar viewpoint condition without movement (NRC), so despite the effect of locomotion, participants were unable to perform at a level comparable with the unmoving, familiar viewpoint.

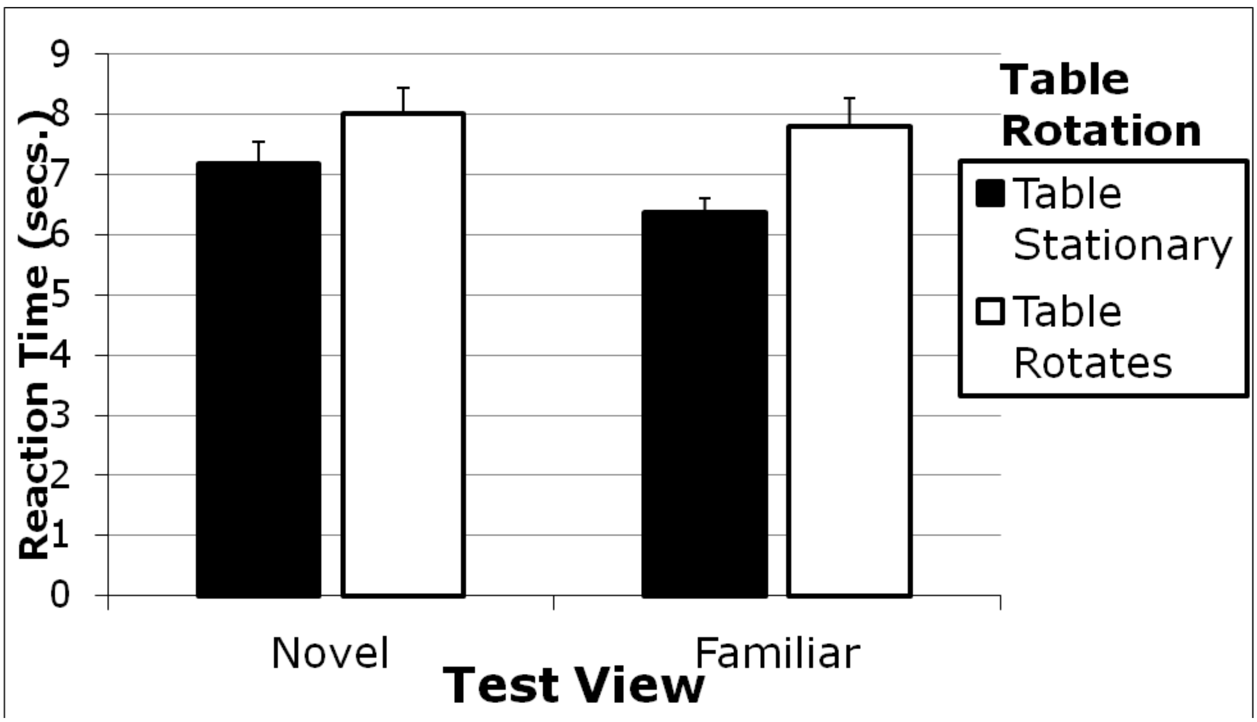

Figure 3 – Reaction time (correct trials) in detecting position change as the function of table rotation and test view

While moving observers can have expectations of what a stationary scene will look like after moving around the environment, due to automatic spatial updating, the case is entirely different when a moving scene is involved. Whether observers are moving or not, no expectations can be made of what a moving scene will look like at the end, as there is no certainty of how much a scene would have moved, not like the certainty of observers knowing exactly how much they have moved. Allowing subjects to see how much the scene has moved, and thus allow subjects to mentally prepare and update what the scene will look like at the test phase, will be explored in Experiment 2.

Like Simons and Wang (1998), we can conclude that subjects were likely encoding experimental layouts from an egocentric frame of reference. This would explain the variation in performance across the four conditions. Had allocentric encoding been involved, it is likely that performance would have been equivalent across the conditions. This will be further explained in the General Discussion when the results of all experiments are taken into account.

From Experiment 1, we concluded that the presence of the external visual indicator could not abolish the difference between the two novel view conditions as shown in Mou et al. (2009). However, it did not directly examine the magnitude of the effect of the visual indicator. It is possible that the effect is not large enough to increase the performance of the table rotation to the level of subject locomotion, but there is still a significant effect. In Experiment 2, we compare directly the performance in conditions with or without the visual indicator to quantify the effect of the visual indicator in the same condition (i.e., the table rotation condition).

Experiment 2

In Experiment 1, we failed to replicate Mou et al.'s (2009) results. The performance in the table rotation condition did not improve to the extent that it was comparable to that in the subject rotation condition. Even though the visual indicator did not improve the performance in the table rotation condition to the level of performance in the subject locomotion condition, the visual indicator might indeed have some beneficial effect. Therefore in Experiment 2, we wanted to further test the effect of the visual indicator by directly comparing conditions with and without the visual indicator.

We once again consider the hypotheses of both Simons and Wang (1998) and Mou et al. (2009), as mentioned in Experiment 1. In the situation where the visual indicator is not present, both would conclude that there should be better performance in the subject rotation condition compared to the table rotation condition but the interpretation would differ. Simons and Wang (1998) would infer that this is due to body-based cues being presented (and used) in the subject rotation condition, while Mou et al. (2009) would infer that this is due to information of the reference direction being provided , through displacement, following active locomotion (and not being presented in the table rotation condition). When the visual indicator is presented, the predicted results of the two groups of researchers now differ. Simons and Wang (1998) would argue that the presence or absence of the visual indicator would not make a difference. Mou et al. (2009) would argue that the visual indicator should now provide a reference direction to the table rotation condition, and thus with the presence of the visual indicator, the performance in the table rotation condition would improve compared to that without.

Even though our first experiment failed to show that the visual indicator improved the performance in the table rotation condition to the level of performance in the subject locomotion condition, we still expected that the visual indicator might have some beneficial effect if we compare conditions with and without the indicator.

Methods

The second experiment was created as a follow-up to the replication experiment (Experiment 1), keeping in mind two key factors. The first was to compare the overall effectiveness of the visual indicator as a reference direction cue, and the second was to make the task easier for subjects. We wanted to make the task easier wherever possible to try to increase overall performance, because performance across all conditions was lower in Experiment 1 compared to the experiments conducted by both Simons and Wang (1998) and Mou et al. (2009). Changes in methods will be described further below.

Subjects

For this experiment, 17 subjects (7 males, 10 females), all undergraduate students from McMaster University, ranging from 18-21 years of age (M = 18.88, SD = 1.08), participated for one course credit.

Materials and Design

The setup for the second experiment was essentially the same as the first experiment with some changes made. Subjects completed one, hour-long session, rather than two, hour-long sessions. For all trials either the table moved or the subject moved 50 degrees to the right as in the first experiment. The direct influence of the visual indicator as a reference direction cue was studied by providing the visual indicator in half of the trials in the test phase. Thus there were a total of four conditions that subjects went through.

The retention phase was decreased in duration from 17 seconds to 15. As with Experiment 1, and in general practice for all experiments, the shortest possible time for the retention phase was selected. This was done to give subjects a short retention time, and to allow them to respond as soon as possible to help avoid subjects' forgetting the layout of objects they memorized in the learning phase.

In the new setup, subjects were provided visual information about the rotation of the table during the retention phase. At the beginning of the retention phase, while the subjects were still blindfolded, in addition to moving one of the objects, the experimenter also covered the table using a large piece of black, circular cardboard, roughly the same size as the table (1 m diameter). To raise the cardboard above the objects on the table, 4 Styrofoam cups (roughly 250 mL volume) were taped onto the edges of the bottom of the cardboard, spread out evenly. Once the cardboard covered the table, the experimenter then tapped the shoulder of the subject to lift up their blindfold. Depending on the condition stated at the start of the trial, the subject moved around the table to 50 degrees to the right, or remained stationary and viewed the table rotating as the experimenter rotated it 50 degrees to the right. To ensure that subjects were clearly seeing the table move at exactly 50 degrees, an indicator, in this case, a bright, coloured slip of paper, was placed on the cardboard at 0 degrees, so that when the table rotated, the slip of paper rotated to 50 degrees (similar to the case of the chopstick). Once the retention phase was over, the experimenter took the piece of cardboard off the table and the subject was then able to view the test phase and give a response.

These changes in experimental method were done to make sure that subjects understood the change of viewpoints. Subjects were able to move themselves without assistance and to actually see the table rotate. Moving themselves gave the subjects more control over their movement. Also, by seeing the covered table explicitly move, subjects were now able to spatially update the scene consciously by following along with the table movement and imagining the scene underneath the cardboard rotate as well. Subjects were able to update the scene by moving, regardless of being blindfolded, but by being blindfolded in the table rotation condition, it would have been harder for subjects to imagine the scene rotating. Seeing the scene explicitly would now make it easier to visualize the layout rotating 50 degrees.

The four conditions that subjects went through were: the table stationary-subject rotation condition without the chopstick (SR), the table rotation-subject stationary condition without the chopstick (TR), the table stationary-subject rotation condition with the chopstick (SRC), and the table rotation-subject stationary condition with the chopstick (TRC) (see Table 2 and Figure 4 for layout of conditions).

Table 2 - Experiment 2 Conditions

Condition	Table at test	Observer at test	Presence of chopstick
SR	0	50 walk	None
TR	50 rotation	0	None
SRC	0	50 walk	During test
TRC	50 rotation	0	During test

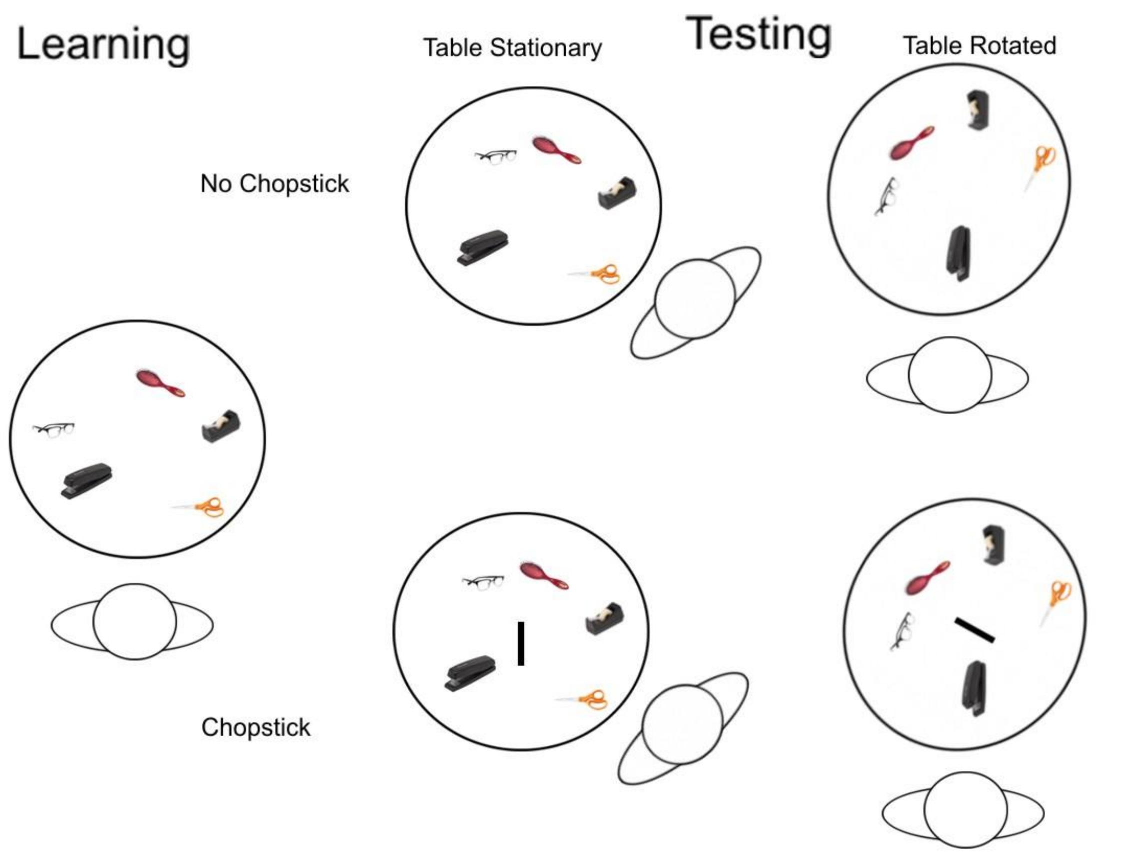

Figure 4 – Experiment 2 Conditions

Results

Within-subjects ANOVA was used to assess the effect of table position and presence of the visual indicator on accuracy. The main effect of table position [$F(1,16) = 24.39$, $p < 0.001$]

was significant. The main effect of identity (presence or absence of visual indicator) [$F(1,16) = 0.025$, $p = 0.875$] was not significant, and more importantly, there was no interaction effect [$F(1,16) = 0.807$, $p = 0.382$] (see Figure 5). For RT, for correct trials, the main effect of table position [$F(1,16) = 48.04$, $p < 0.001$] was significant. The main effect of identity [$F(1,16) = 3.379$, $p = 0.085$] was not significant, and more importantly, there was no interaction effect [$F(1,16) = 0.002$, $p = 0.968$] (see Figure 6). The lack of interaction in both accuracy and RT suggest the visual indicator has no effect in improving the performance of table rotation.

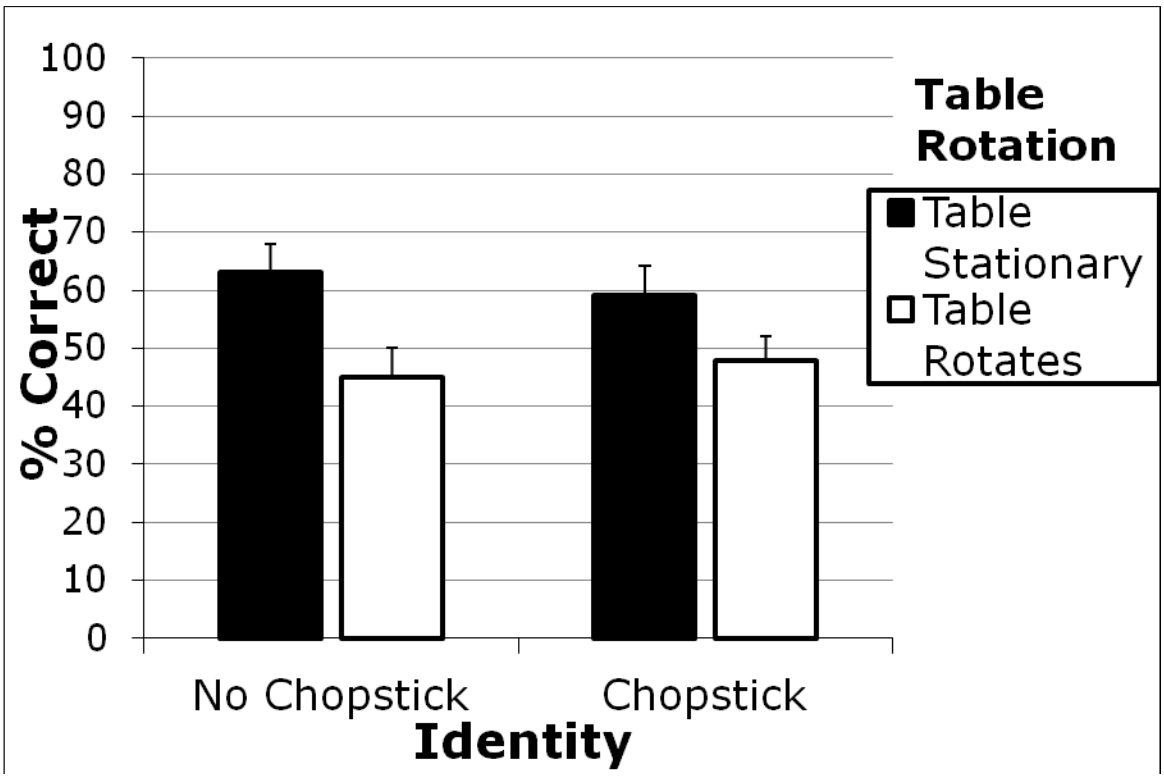

Figure 5 – Accuracy in detecting position change as the function of table rotation and the presence or absence of the chopstick (reference direction cue)

Discussion

We hypothesized that the visual indicator as a reference direction cue would have a significant effect in the comparison between the presence and absence of the indicator, but we once again failed to find that evidence. Instead what we found in the current experiment is consistent with the ideas of Simons and Wang (1998). We found that the presence of the visual indicator (the chopstick) had no effect on performance as a reference direction cue. In the two table rotation conditions the accuracy and reaction time were comparable with or without the visual indicator. The same was true for the two subject rotation conditions. Furthermore, as in Experiment 1, the performance (in both higher accuracy and quicker reaction time) was better when subjects moved, compared to when the table rotated, regardless of the presence or absence of the visual indicator.

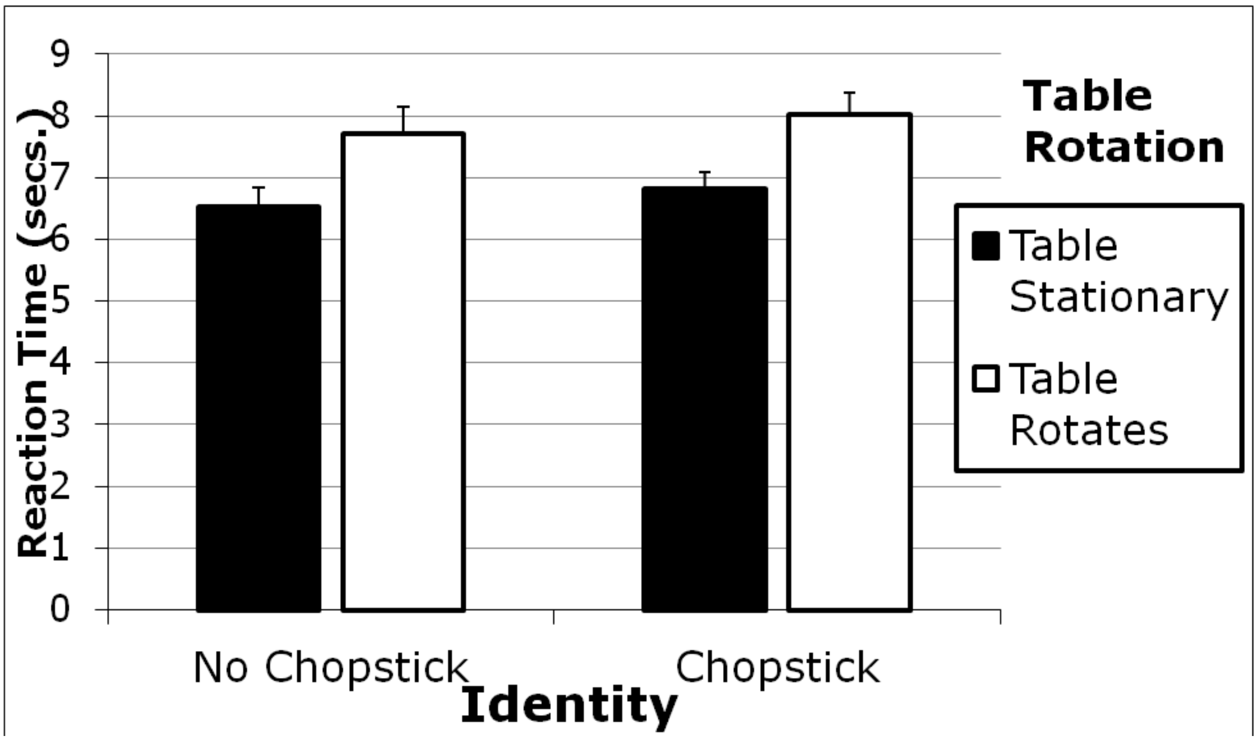

Figure 6 – Reaction time (correct trials) in detecting position change as the function of table rotation and the presence or absence of the chopstick (reference direction cue)

Subjects might not be utilizing the visual indicator as a reference direction cue or were not using it effectively. The fact that subject rotation led to better performance than table rotation could attest to the fact that subjects were still reliant on proprioceptive information. The small drop in accuracy and increase in reaction time when the visual indicator was added to the subject rotation condition (SRC) may reflect some sort of conflict where subjects saw the visual indicator as an extra, unneeded cue. It is possible only one cue is needed, based on the results, and the body-based cues happen to be the default choice, even when an alternative is presented. While the visual indicator did raise the accuracy in the table rotation condition (TRC), this was not significant enough, and the proprioceptive feedback gained from moving was still the superior cue. The increase in reaction time to the presence of the visual indicator could also be explained by the possibility that the cue may have been used, at least in the table rotation condition, and required time to process. Regardless of the presence of the visual indicator, and being able to see the table move, subjects still had difficulty performing the task as they still had a hard time imagining all the objects being shifted 50 degrees. They would have also had to deal with the conflict of the table moving and themselves remaining stationary. The lack of an interaction effect points to the fact that subjects were not using the visual indicator effectively when presented in the table rotation conditions. Therefore we are still seeing an increased cost in viewpoint shift when it is caused by the scene moving compared to the observer moving.

As in Experiment 1, subjects were using body-based cues when available, and were not likely using the visual indicator at all given the differences in performance between the subject rotation and table rotation conditions. Similar to the studies involving real rotation in comparison to imaginary rotation (i.e. Greenauer & Waller, 2008; May, 2004; Wraga et al., 2004), subjects were having greater difficulty in table rotation conditions as they had to imagine the scene rotating away from them, compared to the subject rotation conditions, where they actually rotated. Alternatively, in the table rotation conditions, subjects may imagine themselves moving away from the original viewpoint, but regardless, imagination has to occur to make sense of the viewpoint shift, which is less effective than having rotation occur for real. This is likely due to automatic spatial updating occurring only in the ‘real’ rotation conditions (subject rotation). Imagining the rotation requires more mental effort and thus is prone to more errors.

While it appeared that the visual indicator in our experiment simply was not effective, this may not always be true. As seen in studies involving landmark cues (Burgess et al., 2004; Burgess, 2006, 2008; Byrne et al., 2007; Coluccia et al., 2007; de Vega & Rodrigo, 2001; Holmes & Sholl, 2005; Mou, Liu, et al., 2009; Mou et al., 2006; Shelton & McNamara, 2001; Sholl, 1999; Sun, Chan, et al., 2004; Wang & Spelke, 2000, 2002; Zhang et al., 2013), it is possible for external cues to provide assistance in spatial recognition. As seen in Burgess et al. (2004), a cue-card landmark was used in a similar manner to the visual indicator in our experiments, and would move with the scene (table) for some of the conditions. In these conditions, an effect was found. It may be argued, however, that this experiment had subjects utilizing the cue, whereas in our experiments, the subjects were not using the visual indicator. Also, this cue was present in both study and test phases, whereas our cue was present in only the test phase. This was done to replicate Mou et al.’s (2009) procedure, but also to have an indicator of viewpoint shift rather than a landmark present at all times. Perhaps, the visual indicator is not salient enough for subjects to incorporate it into their mental layout when presented. As mentioned in the landmark studies, a cue is only useful if encoded or incorporated as part of the scene. If seen as an external landmark that has no bearing on viewpoint shift, then a cue will not be utilized. This explains why features on the wall in some of these experiments had no effect on performance as they were not treated as part of the scene. It also helps if a cue is associated with an intrinsic structure of the object layout. Experiment 6 will address having an alternative reference direction cue that is more salient and corresponds to the intrinsic structure of the object layout.

Experiment 1 & 2 Comparison

We wanted to do a quick analysis comparing both experiments 1 and 2, to see if generally the same results were being found, and also to see if the alterations made in the experimental method made any difference.

Results

Further data analysis was done to compare the results from Experiment 1 to Experiment 2. In this case, unequal variance, two-tailed t-tests were used. Only the two novel viewpoint conditions from Experiment 1 were used in this analysis for the comparison with Experiment 2. For the most part, the results were insignificant, even when comparing the grand totals of both experiments which encompassed different conditions for each experiment (53.97% vs. 53.88%). There were two exceptions, those being that performance in the table rotation condition (from Experiment 1) differed significantly from that in the subject rotation with chopstick condition [$t(26.79) = 2.59$, $p < 0.05$], and performance in the table rotation condition (from Experiment 1) also differed from that in the subject rotation without chopstick condition [$t(27.14) = 3.31$, $p < 0.05$].

When comparing reaction time between Experiment 1 and Experiment 2, most of the t-tests were insignificant with one exception. The t-test for the table rotation condition (from Experiment 1) and the subject rotation without chopstick condition [$t(36.43) = 2.83$, $p < 0.01$] was significant.

Discussion

The fact that most of the between experiment comparisons were insignificant means that the data collected for both experiments were from the same population and that both experimental groups were performing at comparable levels, thus there was some consistency.

The few significant comparisons could be a result of the fact that the sample size for Experiment 2 was smaller and was reduced to only one session, thus high performers were able to bring up the average of the results for the different conditions. However, the grand totals for both experiments were almost identical, so this is not likely the explanation. The most likely cause is the fact that subjects in Experiment 2 were now able to move themselves and see the table move with an indicator. This made the task a little easier for subjects to process, as they could update the scene visually while the changes in position were made during the retention phase. For instance, synchronized spatial updating could then occur in the table rotation conditions as the subjects could see the table move, and thus have a more accurate expectation of the scene when presented during the test phase. This would have also led to a slight decrease in reaction time (which was noted in all conditions in Experiment 2 compared to Experiment 1). This change was done to provide an alternative to the automatic spatial updating that occurred in the subject rotation conditions. In this new setup, both conditions now had a source and a means of providing spatial updating. While this change in methods did increase results a bit across all conditions compared to Experiment 1, and two comparisons (one for reaction time) between the two experiments were significantly different, this still does not outweigh the fact that most of the results between Experiments 1 and 2 were within a comparable range for both accuracy and reaction time.

This concludes that while the setup for Experiment 2 may have some minor benefits in making the task easier for subjects, overall the difference is not very significant. What should be taken into consideration, is that the differences that were found between the two experiments show that the setup of Experiment 2 made subjects more accurate (and quicker) in performing tasks in the subject rotation conditions than the table rotation condition from Experiment 1.

Even though the statistical evidence was not very strong in this case, the new experimental method will be employed when it can, to at least offer the chance for subjects to mentally update the scene as they see the table rotate. Experiments where subjects do not need to be blindfolded during the retention phase can use this method. Others, such as experiments manipulating movement, as will be shown in the next set of experiments, will have subjects going to the same endpoint in a variety of ways, thus it is important to remain blindfolded throughout the trials.

Experiment 3

We have showed that, in the table rotation and subjects' stationary condition, the visual indicator as a reference direction cue has failed to show an effect on performance. Moreover, the performance was nowhere near the level of performance of the subject movement condition as shown by Mou et al (2009). The aim of Experiments 3-5 was to test the effect of reference direction (indicated by the visual indicator) in a paradigm where the visual indicator is more likely to show its effect.

In the table rotation condition, observers were stationary (thus with reliable body-based cues indicating the lack of movement). While the table was rotated, subjects might have a hard time to overcome their body-based information to imagine a viewpoint (even if it is visually indicated by the chopstick) which is different from their body facing direction. If, as the viewpoint changes, subjects' body-based information is disrupted, there is a chance that the effect of the visual indicator will be revealed. We thus hoped those conditions would offer a more sensitive measure of the effect of reference direction (indicated by the chopstick). If reference direction is indeed encoded, at least for those conditions with high noise of the orientation/position information of the body, the effect of the reference direction would be more obvious.

Two forms of manipulations of body-based information were implemented while the viewpoint was changed. One condition required subjects to walk a long curved route (as opposed to taking a shortcut) to get to the same endpoint. Subjects walked around the table 310 degrees to the left with the end point equal to that of a 50 degree viewpoint change to the right (the normal subject rotation condition). While this manipulation provided a more subtle form of manipulation of a body-based cue, we also manipulated the body-based cue in a more dramatic and complete fashion. This condition involved disorientation by spinning subjects towards the endpoint rather than having them walk normally. This was done to see whether being disoriented, thus receiving weakened body-based cues, would affect whether the visual indicator would be an effective cue in affecting performance compared to simply being moved to the endpoint in a more linear fashion.

In this experiment, we wanted to investigate whether subjects would now be able to take advantage of the information from the visual indicator of reference direction (chopstick), as the conflicting body-based information is weakened in both of these conditions mentioned. In Experiment 3, we have these two conditions as well as the two novel view conditions (table rotation and normal subject rotation conditions) tested extensively in the literature and in our earlier two experiments. The visual indicator would be presented in all these conditions.

Taking into account the viewpoints of both Simons and Wang (1998) and Mou et al. (2009), we once again come up with different predictions that could occur. Simons and Wang (1998) would predict that once again normal subject rotation should have the best performance and table rotation should have the worst performance. When considering both altered subject rotation conditions, the performance should be less than that of normal subject rotation, since the body-based cues involved are weakened, or at most unreliable, but performance of the two conditions may still be higher than that of table rotation, because they still involve body-based cues (in a diminished form) and they do not have a conflict of having a stationary body and a moving scene. The proprioceptive information used in the table rotation condition would be detrimental as the body would be notified as having not been moved, yet a viewpoint shift occurred with the scene having been rotated. The proprioceptive information would have to be ignored to do the task in this case. Of the two altered subject rotation conditions, taking a longer route to get to the same endpoint might lead to greater accuracy, because subjects could potentially keep track of their movement. In contrast, Mou et al. (2009) would give a completely different prediction. Rather than having the difference in performance in these four conditions, they would predict comparable performance in all these conditions due to the presence of the visual indicator in all the conditions.

Based on the results of our previous two experiments, we hypothesized that the table rotation condition would lead to the worst performance while the normal subject locomotion condition would lead to the best performance. The performance for the two altered subject rotation conditions will be comparable to that of the subject (normal) locomotion condition.

Methods

Subjects

For this experiment, 40 subjects (22 males, 18 females), all undergraduate students from McMaster University, were tested ranging from 17-26 years of age (M = 18.50, SD = 1.58), and all participated for one course credit.

Materials and Design

The setup for the third experiment was essentially the same as the first experiment with some changes made, notably the task conditions. Like Experiment 2, subjects only had to go through a single one hour session, instead of two. Since the main aim of the experiment was manipulating observer locomotion and seeing the effects on performance, three of the four conditions involved observer locomotion of some sort, while the remaining condition involved only table rotation. Thus once again, the familiar viewpoint conditions were dropped and all conditions in this experiment involved a novel viewpoint.

The four conditions that all subjects went through were: the table rotation-subject stationary condition with the table being rotated 50 degrees to the right (TRC), the normal table stationary-subject rotation condition with the subjects moving 50 degrees to the right (SRC), the table stationary-subject rotation condition with subjects being moved 310 degrees to the left around the table (hence ending up in the same endpoint as SRC) (LSRC), and the table stationary-subject rotation condition with the subjects being disoriented by being spun three times and ending up 50 degrees to the right of the table (DSRC) (see Table 3 and Figure 7 for layout of conditions).

Table 3 - Experiment 3 Conditions

Condition	**Table at test**	**Observer at test**	**Presence of chopstick**
TRC	50 rotation	0	During test
SRC	0	50 walk	During test
LSRC	0	310 walk	During test
DSRC	0	50 disoriented walk (spin)	During test

It should be noted that subjects were able to recognize that they were at the same endpoint for all subject rotation conditions due to the instructions given but also due to the fact that the visual indicator was pointing to the spot where subjects first memorized the objects (which was always 50 degrees to the left of them). The instructions given ensured that every subject from the start knew that they would end up in the same endpoint during the test phase for the subject movement conditions, and thus make it even for everyone (if this was not clarified from the start, subjects would likely figure out on their own that they were being moved to the same endpoint, but some would figure this out sooner than others).

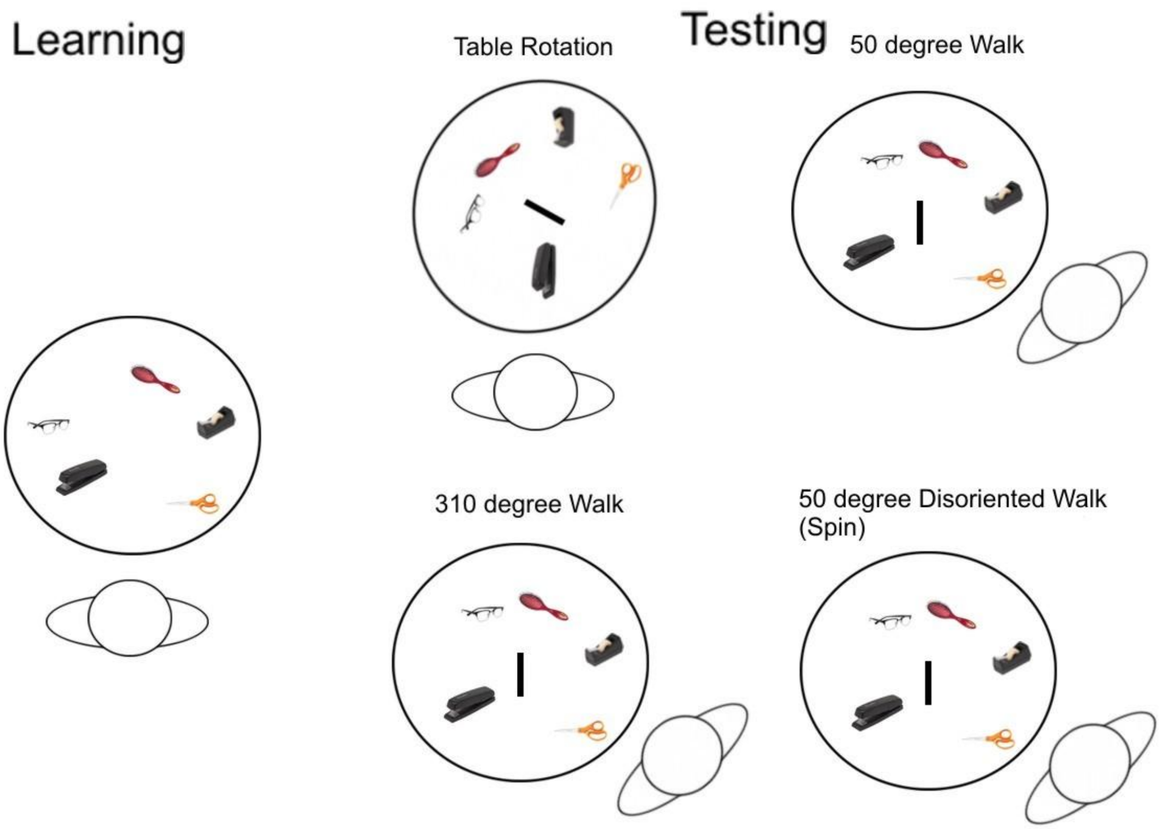

Figure 7 – Experiment 3 Conditions

The other changes in the design of this experiment compared to Experiment 1 included the retention duration. As it took a bit longer to move the subjects during this experiment, the retention phase was increased in duration from 17 (in Experiment 1) to 20 seconds in this Experiment. During the retention phase, after one of the objects was moved, one of the following steps would occur depending on the condition: the blindfolded subject would remain stationary and the table was rotated 50 degrees to the right, the table remained stationary and the subject was moved 50 degrees to the right, the subject would be guided around the table 310 degrees to the left, or the subject would be spun three times clockwise while at the same time being moved 50 degrees to the right. For the latter three conditions, regardless of how subjects were moved, it should be clarified once again that the table was always stationary and that subjects always ended up in the same endpoint during the test phase (that being 50 degrees to the right of the starting position).

Results

Paired, one-tailed t-tests were used to evaluate performance accuracy. The comparisons of the three subject movement conditions with the table rotation condition (TRC) all proved to be statistically significant, including the normal 50 degree subject rotation condition (SRC) [$t(39) = 5.09$, $p < 0.001$], the 310 degree subject rotation condition (LSRC) [$t(39) = 2.42$, $p < 0.05$], and the disorientation condition (DSRC) [$t(39) = 3.81$, $p < 0.001$]. When each abnormal walking condition was compared to the normal subject rotation condition (SRC), the difference between LSRC was significant [$t(39) = 1.93$, $p < 0.05$], but not so with DSRC [$t(39) = 0.472$, $p = 0.320$].

Since five t-tests had been performed, the criterion for level of significance for the p-value could be set to 0.01. In that case, the performance for normal walking and disorientation was still better than table rotation (see Figure 8).

For RT, for correct trials, the comparisons with the table rotation condition (TRC) all proved to be statistically significant, those being the normal 50 degree subject rotation condition (SRC) [$t(39) = 6.22$, $p < 0.001$], the 310 degree subject rotation condition (LSRC) [$t(39) = 5.20$, $p < 0.001$], and the disorientation condition (DSRC) [$t(39) = 3.22$, $p < 0.01$]. When the abnormal movement conditions were compared with the normal subject rotation condition (SRC), it was found that the difference between LSRC and SRC was insignificant [$t(39) = 1.39$, $p = 0.086$], but the difference between DSRC and SRC was significant [$t(39) = 3.62$, $p < 0.001$].

Since five t-tests had been performed, the criterion for level of significance for the p-value could be set to 0.01. Even with the adjustments, the differences found remained statistically significant (see Figure 9).

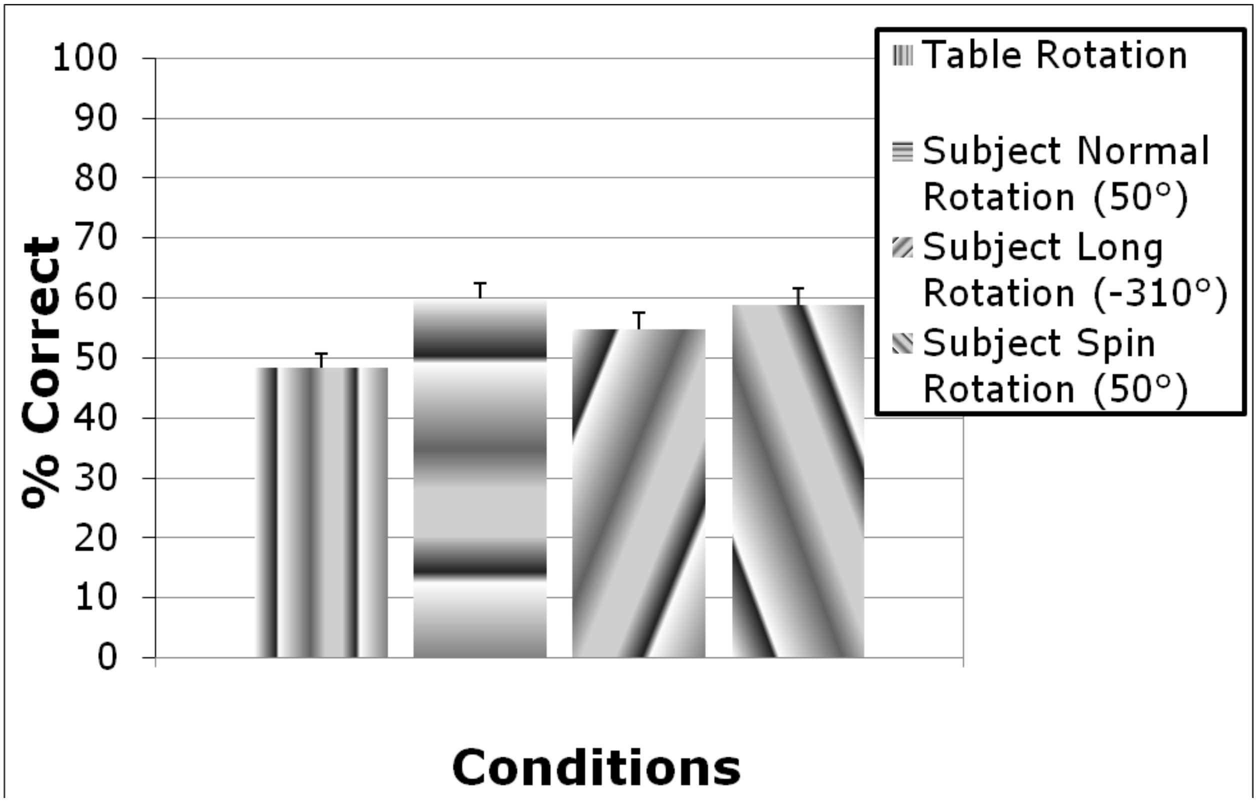

Figure 8 – Accuracy in detecting position change as the function of table or subject rotation

Discussion

Simons and Wang (1998) would predict that there would be a difference in performance amongst these conditions, with normal subject locomotion over a short path being better than a longer route, which in turn would be better than disorientation, which would then be better than the table rotating. Mou et al. (2009) would offer a different perspective, and suggest that in the absence of a cue for reference direction, all conditions should have comparable performance.

Consistent with the results shown in Experiments 1 and 2, in this Experiment, with the presence of the visual indicator, subjects also had better performance (more accurate and quicker in reaction time) in subject (normal) locomotion conditions compared to that in the table rotation condition. These results were consistent with the view of Simons and Wang (1998) but not with the view of Mou et al (2009).

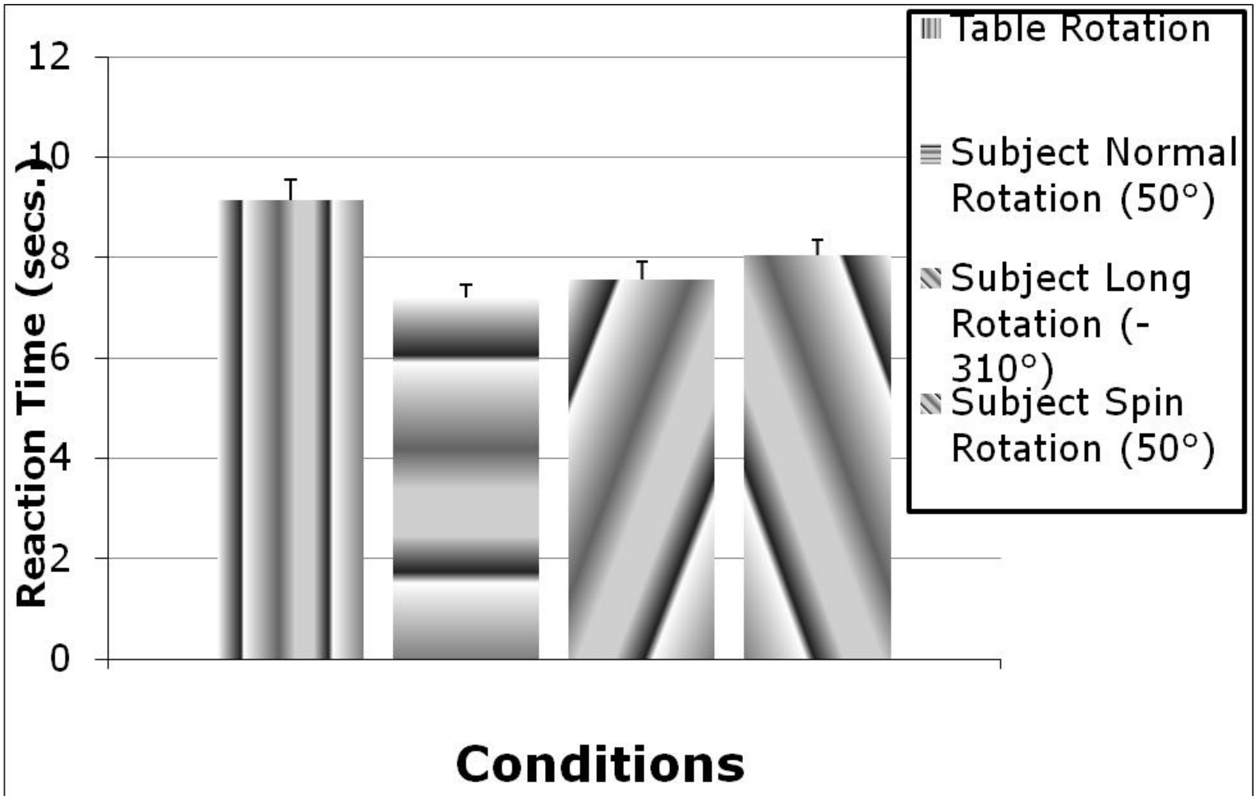

Figure 9 – Reaction time (correct trials) in detecting position change as the function of table or subject rotation

The focus in this experiment was the performance in the other two manipulated locomotion conditions. It appeared that the subjects' performance in disorientation was better than that of the table rotation condition, but not so with the long walk. Multiple factors could have led to such results. The visual indicator could have facilitated the recovery of reference direction. Alternatively, the residual body-based cues could play a role too in achieving the spatial updating.

The results of the comparison between the condition involving normal locomotion over a short path and the other two conditions involving manipulated movement were relatively similar.

At this point, it is hard to isolate the effect of the visual indicator as there is no baseline data for the conditions without the visual indicator. This effect will be examined separately in Experiments 4 and 5.

One notable observation is that there is often a general correlation where an increase in accuracy leads to a decrease in reaction time, so that subjects who are more accurate on a condition tend to give a faster response. Indeed, this is what has been found so far in the past two experiments, and what we expect to find in future experiments. We may infer that this may be, because subjects may find one condition easier compared to another. If a condition is considered easier then subjects are more likely to give an accurate and quick response. This may be the case for the subject rotation conditions so far. Part of this ease is due to automatic spatial updating, which can be used effectively in the subject rotation conditions. Likewise if a condition is deemed more difficult, subjects are likely to be more inaccurate with their response and also take longer with coming up with a response. This may be the case for the table rotation conditions so far. Since we are not always finding this general trend in this experiment, we must explore the individual conditions to give reason for the results found.

Subjects who were disoriented by spinning, have a high accuracy but a slow reaction time. A possible explanation for this is simply that the disoriented subjects needed a quick recovery time before focusing on the task at hand. They had to reorient themselves to evaluate where they were in the experimental environment, but once that was done, subjects were able to give an accurate response. This may be due to the fact that while locomotion was disoriented in this case, it still had some reliability. As mentioned, subjects were not just spun, but were also moved 50 degrees to the right at the same time. Even though the spinning disoriented a normal linear trajectory, subjects may still have received useful body-based information indicating to them that they moved only 50 degrees. In this sense, the disorientation may not have been effective enough in disrupting the body-based information.

A major limitation of this experiment is there is no comparison group to compare each condition where the visual indicator is not present. It is possible that having this comparison group would make no difference, and that subject rotation would still yield a better performance compared to table rotation. An alternative explanation though could be applied to explain the results, and demonstrate that the visual indicator actually did have an effect (at least on the two alternate subject rotation conditions). We can conclude at least, when considering the previous experiments, that the visual indicator as a source of reference direction, did not have an effect on normal subject rotation, because body-based cues were used instead, and did not have an effect on table rotation, as there was the conflict between a stationary body and a shift in viewpoint caused by scene rotation. In the two altered subject rotation conditions, it is possible that the reason subjects in these conditions yielded a better performance than the table rotation condition was because they did not have conflicting body-based information, since they did not have reliable body-based information to use, and were therefore able to use the visual indicator without conflict. Thus by eliminating one source of reference direction (body-based cues) subjects were able to use the alternative (visual indicator) more effectively (than in the table rotation condition), and therefore the conflict of having two sources of reference direction was eliminated. Experiments 4-5 will look into controlling this issue by comparing each of the altered subject rotation conditions with and without the visual indicator.

Experiment 4

In Experiment 4, we wanted to explore further the effects of disorientation in comparison to normal locomotion, and investigate whether the addition of a visual indicator representing reference direction, really did have an effect. Thus like Experiment 2, we investigated the effect of the visual indicator directly by comparing its presence and absence with both conditions (walking and disorientation). As found in Experiment 3, with the visual indicator, performance (at least accuracy) following disorientation was comparable with normal locomotion, but whether this was caused by having a visual indicator or something else, was investigated in the current experiment.

When we consider the theories of Simons and Wang (1998) and Mou et al. (2009), both would make the same predictions in the situation involving the absence of the visual indicator. Both would argue that walking should lead to better performance (greater accuracy and faster reaction time) than disorientation (spinning). Simons and Wang (1998) would say this is because walking has useful body-based information compared to the unreliable body-based information found in disorientation. Mou et al. (2009) would say this is because walking has a source of reference direction while being disoriented does not. When the visual indicator is introduced, Mou et al. (2009) would have a different prediction. While Simons and Wang (1998) would argue that the visual indicator does not matter, and that better performance should still be found in both walking conditions compared to the disorientation conditions, Mou et al. (2009) would argue that the visual indicator is a reliable source of reference direction, and the disorientation condition with the presence of the visual indicator should have better performance than that without.

We hypothesized the presence of the visual indicator, the chopstick, would lead to better performance than that when it was absent for the disorientation condition. The benefit of the visual indicator would be prominent now in the disorientation condition with the absence of body-based cues.

Methods

Subjects

For this experiment, 22 subjects (6 males, 16 females), all undergraduate students from McMaster University, were tested ranging from 18-20 years of age (M = 18.41, SD = 0.72), and all participated for one course credit.

Materials and Design

The setup for the fourth experiment was essentially the same as the third experiment, the only difference being the conditions. The four conditions that all subjects went through were: walking without the chopstick (SR), being disoriented (spun) without the chopstick (DSR), walking with a chopstick present (SRC), and being disorientated (spun) with the chopstick present (DSRC) (see Table 4 and Figure 10 for layout of conditions). Every condition ended up with the subject being 50 degrees to the right away from the original study position, around the table, during the test phase. It should be noted that none of the conditions involved table rotation.

Table 4 - Experiment 4 Conditions

Condition	Table at test	Observer at test	Presence of chopstick
SR	0	50 walk	None
DSR	0	50 disoriented walk	None
SRC	0	50 walk	During test
DSRC	0	50 disoriented walk	During test

Results

Within-subjects ANOVA was used to compare accuracy across the four conditions. The main effect of subject rotation (walking or spinning) [$F(1,21) = 1.67$, $p = 0.210$] was not significant. The main effect of identity (presence or absence of the visual indicator) [$F(1,21) =$ 3.01, $p = 0.097$] was also not significant, and more importantly, there was no interaction effect [$F(1,21) = 2.15$, $p = 0.157$] (see Figure 11).

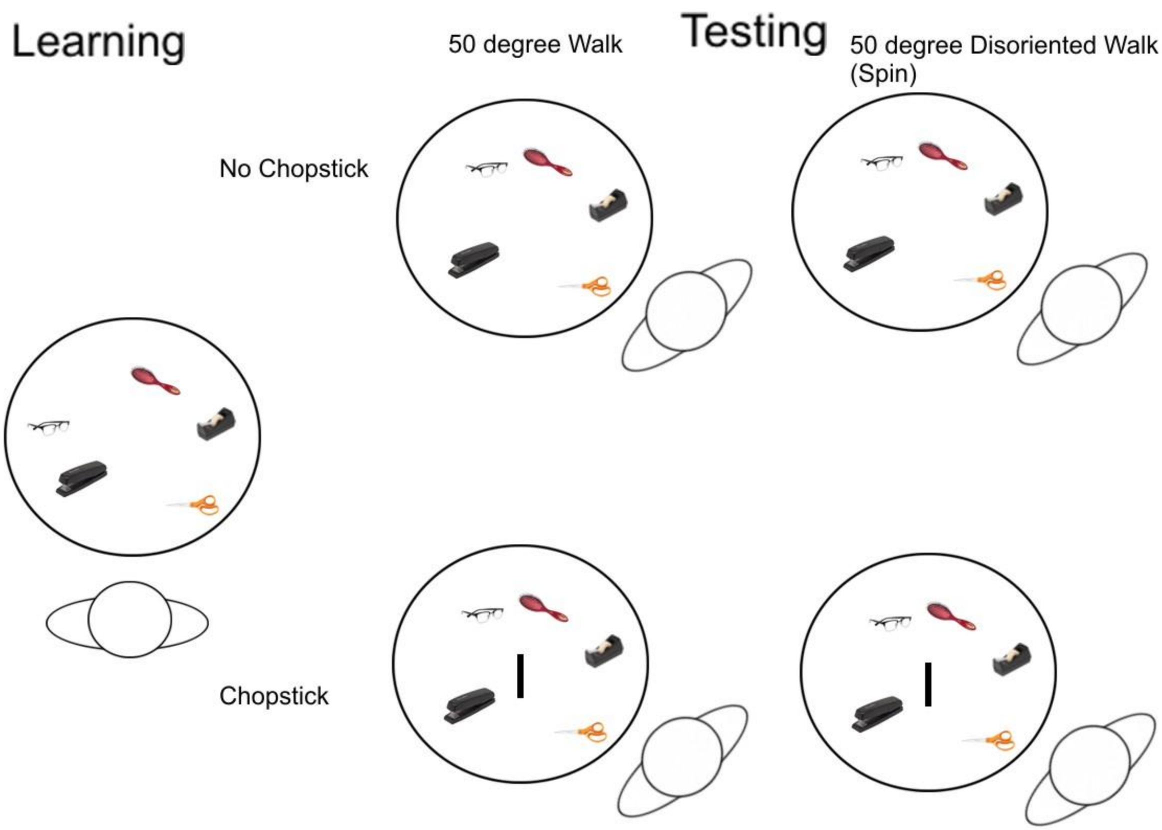

Figure 10 – Experiment 4 Conditions

Even though the main effect of walking was not significant in ANOVA, the two conditions without the visual indicator (SR and DSR) appeared to be different (the paired, one-tailed t-tests) [$t(21) = 1.82$, $p < 0.05$], suggesting normal walking did have some advantage over spinning. However, this was not the case when comparing the two conditions (normal walking vs. disorientation) with the visual indicator (SRC and DSRC) [$t(21) = 0.048$, $p = 0.481$]. This contributes why there was no main effect of walking in ANOVA.

For RT in correct trials, within-subjects ANOVA was performed. The main effect of subject rotation (walking or spinning) [$F(1,21) = 8.03$, $p < 0.01$] was significant. The main effect of identity (presence or absence of visual indicator) [$F(1,21) = 2.07$, $p = 0.165$] was not significant, and there was no interaction effect [$F(1,21) = 0.0081$, $p = 0.929$] (see Figure 12).

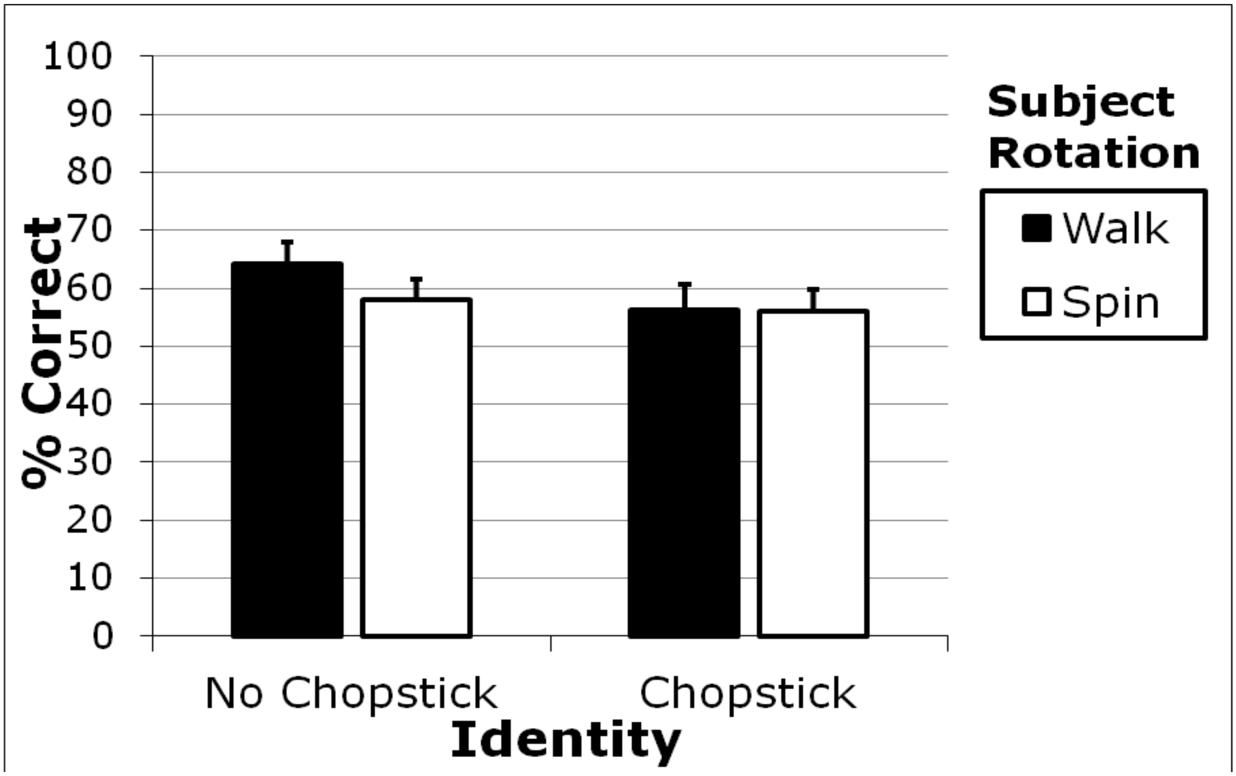

Figure 11 – Accuracy in detecting position change as the function of subject rotation and the presence or absence of the chopstick (reference direction cue)

Discussion

For the current experiment, we had made two main hypotheses. One was the absence of the visual indicator should result in there being a better performance (greater accuracy and quicker reaction time) in walking compared to being disoriented (spun). The second hypothesis was that performance for the disorientation condition would be better with the inclusion of the visual indicator. The first hypothesis was generated from the idea of either Simons and Wang (1998) or Mou et al. (2009). Both theories would predict that without the visual indicator, walking would have better performance than that of disorientation. When the visual indicator was provided, Simons and Wang (1998) would predict that walking should still have better performance than that of disorientation due to the benefit of body-based cues. However, based on Mou et al. (2009), these two conditions should have comparable performance because of the benefit of the visual indicator as a source of reference direction. If the visual indicator cannot generate a large enough effect to make performance in disorientation comparable to that of normal walking, in the disorientation condition, the presence of the visual indicator would have a better performance than without.

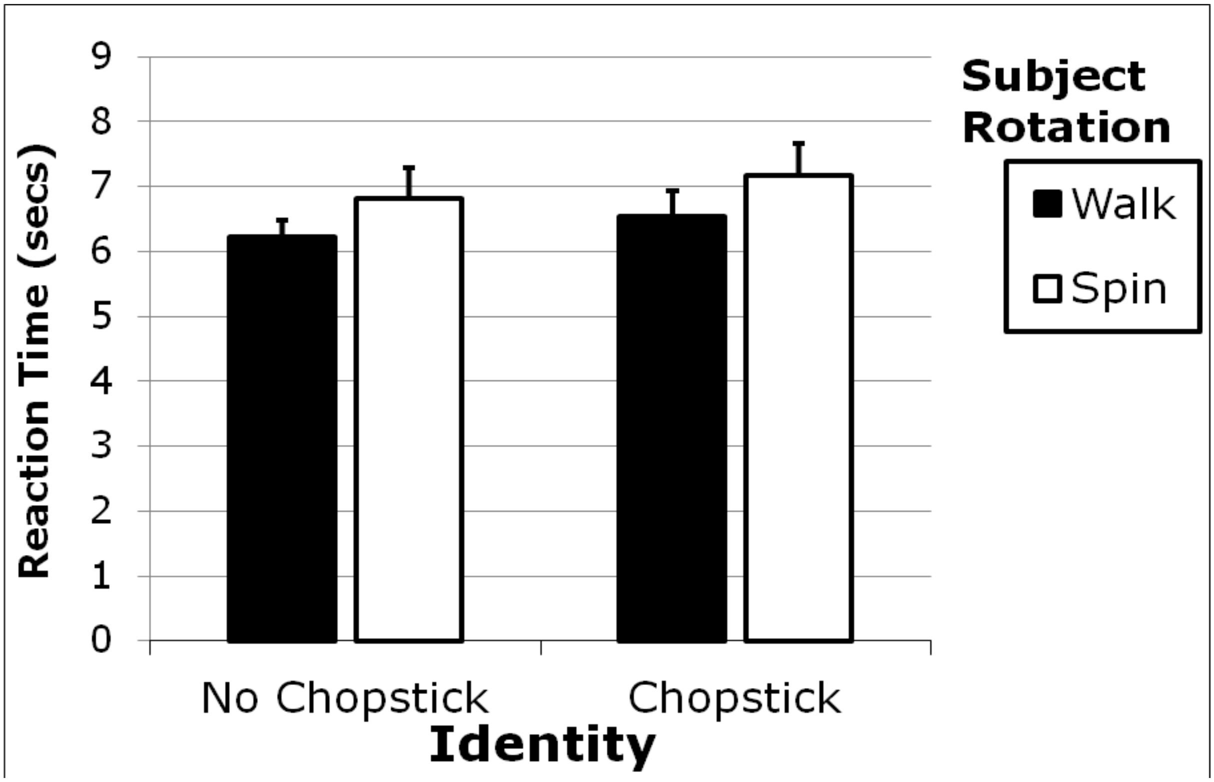

Figure 12 – Reaction time (correct trials) in detecting position change as the function of subject rotation and the presence or absence of the chopstick (reference direction cue)

In the experiment, we successfully demonstrated that, without the presence of the visual indicator, performance in the walking condition was significantly better compared to that in the disorientation condition. However, the presence of the visual indicator failed to improve the performance in the disorientation condition. This is demonstrated by the fact that no interaction effect was found, and thus the visual indicator was not having an effect on disorientation.

It is important to point out that, when the visual indicator was present, the accuracy was low for both walking and disorientation compared to that when the visual indicator was absent.

Therefore the comparable accuracies between walking and disorientation are due to the significantly impaired performance in the walking condition rather than enhanced performance in the disorientation condition[$t(21) = 2.03$, $p < 0.05$] (see Figure 11). It may have appeared at first that we finally replicated Mou et al.'s (2009) findings regarding the visual indicator, since it appeared to alleviate the accuracy of both walking and disorientation conditions. The appearance is deceiving when we consider the impairment to walking when the visual indicator was present.

Taking into account the disorientation conditions, we found no significant difference between them regarding accuracy, and thus the visual indicator appeared to have no noticeable effect. If the reference direction theory, pertaining to the visual indicator, had worked, we would have seen an increase in performance in the disorientation condition, and not, as mentioned earlier, impairment in performance in the walking condition. When looking at the accuracy of the disorientation conditions with and without the visual indicator, we see little difference (56.1% vs. 58.0%, respectively). This is a stark contrast to when we compare this to the two walking conditions. When the visual indicator was present, subjects were 56.2% accurate, but when the visual indicator was absent, subjects were 64.2% accurate (see Figure 11).

The findings of Experiment 4 replicate with the previous findings of Experiment 3 regarding walking in comparison to disorientation conditions with the visual indicator present. There was no difference observed between the two conditions regarding accuracy. For reaction time measure, subjects were faster in the walking conditions than that in the disorientation conditions.

The fact that the visual indicator actually decreased accuracy when presented after subjects had walked may be due to a mental conflict regarding two redundant sources of reference direction. Subjects would have to analyse rather quickly what source had higher accuracy and use that to perform the experimental task. We can eliminate the possibility that subjects were using the visual indicator over their body-based cues and that this choice led to the decrease in performance, since subjects were not using the visual indicator where it mattered most in the disorientation conditions. What is questionable is that if subjects were faced with a mental conflict of having redundant sources, then there should also be an increase in reaction time and not just error. The simplest alternative is that subjects may have been slightly overwhelmed or confused by the presence of the visual indicator, but still responded rather quickly. As of yet, there is no definitive answer as to why the results came out the way they did.

After running subjects, we would ask them a few questions about the experiment to help make sense of the results collected. When asked about whether they found the visual indicator useful, most replied that they did not, and some even said that it left them confused. It should be noted that at the start of the experiment, subjects were notified of the use of the visual indicator. For those subjects who studied the layout of the objects as a whole, such as memorizing the objects as a figure, the subjects said that when the visual indicator was presented during the test phase, it disrupted their internal image of the layout that they had previously memorized. It appears then that the visual indicator was simply an external cue that was not compatible with subjects' internal representation of the layout of objects. Trying to combine the two seems to be more of a detriment than a benefit, due to the redundancy of reference direction information. These findings parallel studies involving reading and studying a map in comparison to manoeuvring around an environment (Christou & Bülthoff, 1999; Coluccia et al., 2007; Rieser et al., 1994; Roskos-Ewoldsen et al., 1998; Shelton & Gabrieli, 2002; Shepard & Hurwitz, 1984; Sholl, 1999; Sun, Chan, et al., 2004; Wang & Spelke, 2000, 2002). There are two main perspectives used to memorize a layout and these correspond to a frame of reference. One perspective, which was used by subjects who memorized the layout as a whole figure, is the survey perspective. This perspective focuses on the layout as a whole, and as such, encodes the layout as a whole, like looking at landmarks on a map but remembering them as corresponding to the whole map. Thus subjects using this perspective would look at the five objects and memorize them as forming an abstract five-sided figure. This entails that subjects would be encoding the scene from an allocentric frame of reference. Thus regardless of how a viewpoint shift occurred, subjects may be able to have high performance as they would be able to recall the layout in an effective manner. This would also explain why the visual indicator would be detrimental as subjects would already have a mental layout of a five-sided figure which would be disrupted by the presence of the visual indicator after the scene was encoded. The other perspective, which is not as efficient in this experiment, given the limited time in the study phase, is the route perspective. This perspective is connected to the egocentric frame of reference as subjects using this perspective would memorize the layout in more detail and encode where each object is relative to all the other objects and where each object is relative to the observer. Subjects trying to use this perspective in our experiment would most likely fail (hence have worse performance) as there is not enough time to build the connections of how the objects are interconnected. This perspective is generally used in experiments, such as some of the ones in the above mentioned studies, where subjects are given ample time to view and manoeuvre their spatial environment. It is difficult to know for sure what perspective subjects were taking in encoding the layout, as the most information we can gather is subjects' verbal responses. It should be noted that some of the subjects who explicitly stated that they memorized the layout in a manner described in the survey perspective, did have higher performance across all conditions, compared to other subjects. Future studies can look into these perspectives and try to have a more controlled setting where subjects are likely to only use the route or survey perspective.

In this experiment, we once again failed to find evidence that the presence of a visual indicator of reference direction produced better performance than its absence, even when subjects were disoriented. However, it is important to realize that while disorientation potentially could offer a more complete disruption of body-based cues, subjects might be too disoriented in the task in that their performance might not completely reflect what they do in normal circumstances. In the next experiment, we will now examine a scenario which involves a more gentle form of manipulation of movement, a normal form of locomotion yet over a longer route to get to the same endpoint.

Experiment 5

Similar to Experiment 4, in Experiment 5 movement of the subjects was also manipulated so that we could compare the change of viewpoint caused by normal spatial updating with change of viewpoint caused by less optimal ways. In the current experiment, we compared normal walking of 50 degrees (a short or direct path) with walking of 310 degrees (a longer or indirect path). We were essentially comparing two different paths to the same endpoint, one straightforward, and the other much longer, and seeing if the visual indicator of reference direction had a differential effect on these two conditions. In addition to the movement length, we also manipulated the presence or absence of the visual indicator, and made the overall experiment a 2x2 design like the previous experiments.

When we consider the theories of Simons and Wang (1998) and Mou et al. (2009), both would make the same predictions in the situation involving the absence of the visual indicator. Both would argue that walking a direct path should lead to better performance (greater accuracy and faster reaction time) than walking an indirect path. Simons and Wang (1998) would say this is because direct walking has useful body-based information compared to the unreliable body-based information found in the unnecessary indirect path. Mou et al. (2009) would say this is because direct walking has a source of reference direction while indirect walking does not. When the visual indicator is introduced, both sides now differ. Simons and Wang (1998) would argue that the visual indicator does not matter, and that better performance should still be found in both direct walking conditions compared to the indirect walking conditions. As well, both direct walking conditions should be comparable in performance, and both indirect walking conditions should be comparable in performance. Mou et al. (2009) would argue that the visual indicator is a reliable source of reference direction, and therefore the conditions that have it should have better performance than those without.

We hypothesized that, when the visual indicator was not present, subjects would have a better performance in the short direct path condition. If the reference direction theory was correct, with the presence of the visual indicator, the performance in the long indirect path condition would be better than that without the indicator and the benefit might even reach the level comparable to that of the short path condition.

Methods

Subjects

For this experiment, 23 subjects (6 males, 17 females), all undergraduate students from McMaster University, were tested ranging from 18-27 years of age (M = 18.95, SD = 1.86), and all participated for one course credit.

Materials and Design

The setup for the fifth experiment was essentially the same as the third experiment, the only difference being the conditions. The four conditions that all subjects went through were: walking 50 degrees to the right without a chopstick (SR), walking 310 degrees to the left without a chopstick (LSR), walking 50 degrees to the right with the chopstick present (SRC), and walking 310 degrees to the left with the chopstick present (LSRC) (see Table 5 and Figure 13 for layout of conditions). It should be noted that none of the conditions involved table rotation.

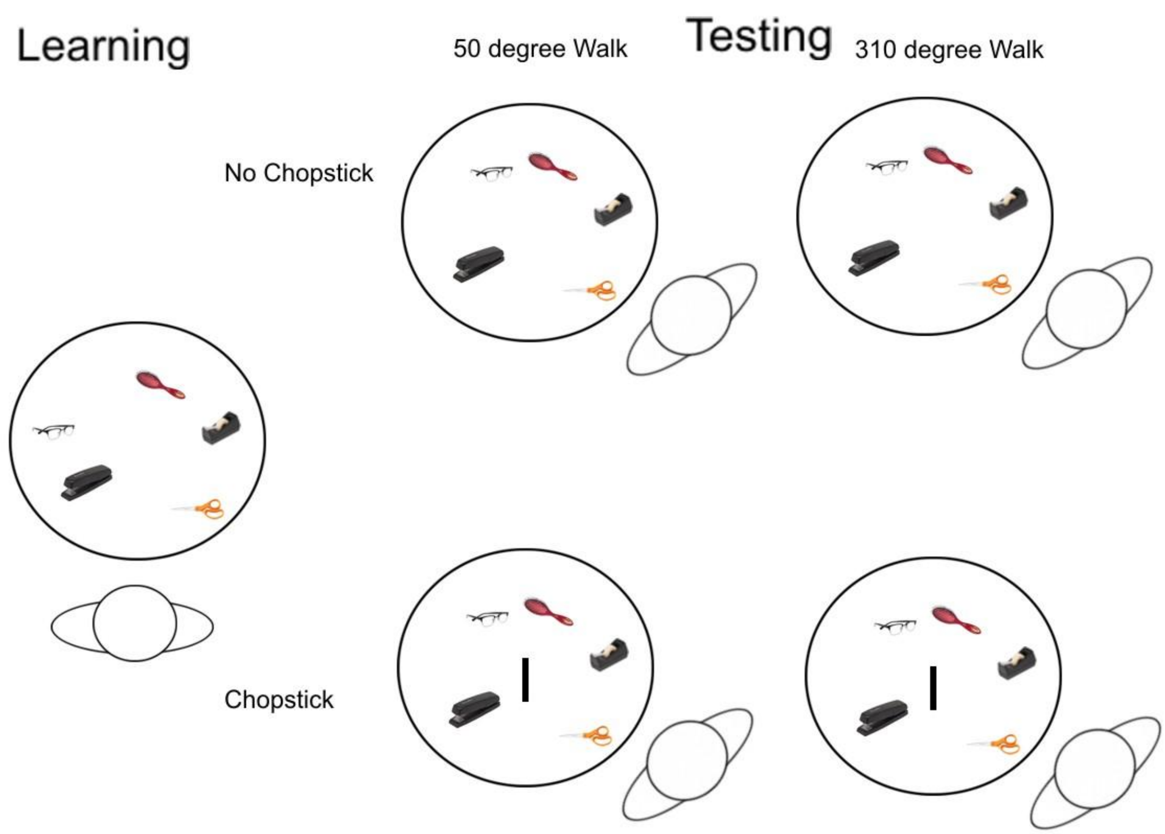

Figure 13 – Experiment 5 Conditions

Results

One subject was removed in the final analysis as she did not complete the experiment and yielded low accuracy scores.

Table 5 - Experiment 5 Conditions

Condition	Table at test	Observer at test	Presence of chopstick
SR	0	50 walk	None
LSR	0	310 walk	None
SRC	0	50 walk	During test
LSRC	0	310 walk	During test

Within-subjects ANOVA on accuracy revealed no significant main effect of subject rotation (50 or 310 degrees) [$F(1,21) = 3.57$, $p = 0.073$], no main effect of identity (presence or absence of chopstick) [$F(1,21) = 0.119$, $p = 0.733$], and more importantly, no interaction effect [$F(1,21) = 2.53$, $p = 0.127$] (see Figure 14).

For RT, for correct trials, the main effect of subject rotation (50 vs. 310 degrees) [$F(1,21) = 8.87$, $p < 0.01$] was significant. The main effect of identity (presence vs. absence of the visual indicator) [$F(1,21) = 0.557$, $p = 0.464$] was not significant, and more importantly, there was no interaction effect [$F(1,21) = 0.616$, $p = 0.441$] (see Figure 15).

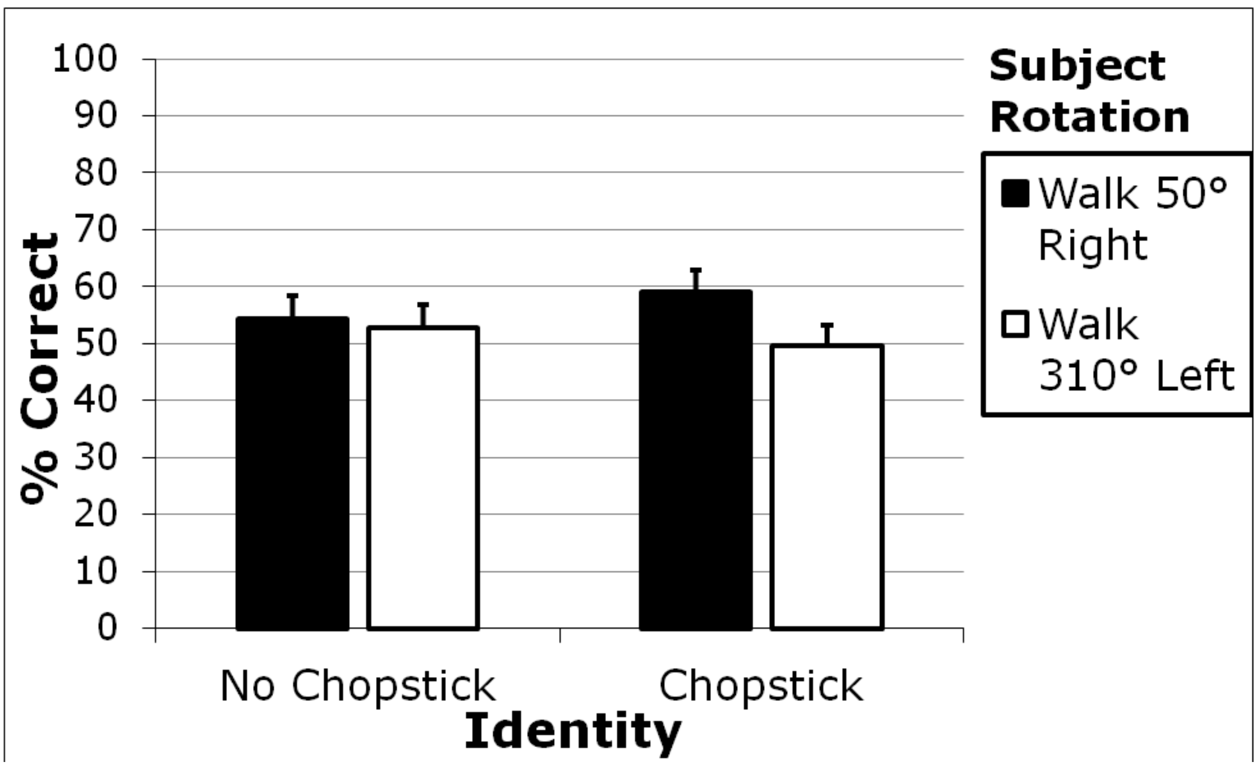

Figure 14 – Accuracy in detecting position change as the function of subject rotation and the presence or absence of the chopstick (reference direction cue)

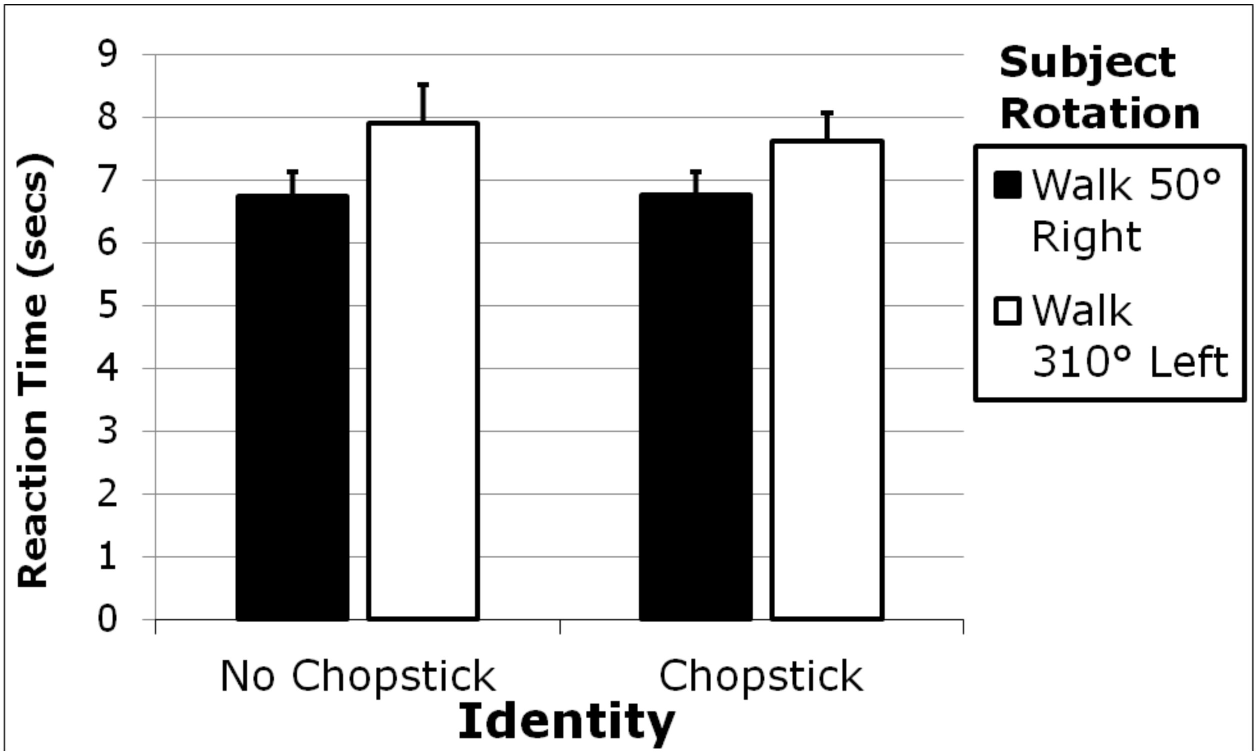

Figure 15 – Reaction time (correct trials) in detecting position change as the function of subject rotation and the presence or absence of the chopstick (reference direction cue)

Discussion

For the current experiment, we had two main hypotheses. First without the visual indicator, there should be a better performance (greater accuracy and quicker reaction time) in the short direct walking condition compared to the longer indirect walking condition. The second hypothesis was that, for the longer indirect walking condition, the inclusion of the visual indicator should lead to better performance compared to the condition without the indicator. While the first hypothesis can be inferred from both of the theories of Simons and Wang (1998) and Mou et al. (2009), the second hypothesis would be a generated form of an idea from Mou et al. (2009).

In the experiment, the reaction time data were consistent with the first hypothesis, although the data for accuracy only showed the same trend, without showing a significant result.

We did not have evidence to support the second hypothesis, in other words, the visual indicator did not improve performance in any of the walking conditions.

Subjects who moved 310 degrees around the table were aware that they were at the same endpoint as if they had been moved 50 degrees in the opposite direction, yet despite this, accuracy decreased. It may be that despite having this knowledge of being moved to the same endpoint, subjects were receiving body-based information that they had been moved 310 degrees, and had to deal with both sources of information that would be conflicting. This body-based information would be unnecessary because it is logical to think that one is 50 degrees away from the starting position than 310 degrees away in the opposite direction around a circular table. Thus the body-based information has to be ignored, as it conflicts with this acknowledgment of being 50 degrees away in the other direction. This cognitive conflict would have resulted in the lower performance.

After running subjects, we would ask them a few questions about the experiment to help make sense of the results collected, the same as in Experiment 4. The same general responses were collected in that many subjects said they did not use the visual indicator, and some even saying it was a distracter.

Based on the results of the current experiment, it is reasonable to claim that body-based information gathered from walking is more beneficial than a visual indicator acting as a reference cue. We can reject the proposal that having a reference direction cue (visual indicator) is better than having no reference direction cue, as subjects did not appear to utilize the cue in the indirect walking condition.

All of the previous experiments thus far, have proven that the effect of the visual indicator (chopstick) as a cue of reference direction was not sufficient in changing performance even in conditions with unreliable body-based information. This is likely due to subjects not focusing on or utilizing the visual indicator, as based on some of the responses collected after the current experiment and Experiment 4.

Even with these results, at this point, one may not want to completely dismiss the theory about the use of a reference direction cue (alternative to a body-based cue), as subjects were not utilizing the cue given. Had it been utilized and not seen as something external, or at most, a distracter, the results of the experiments may have been different. A different sort of cue, something that can be internalized in subjects' mental image of the object layout and thus be utilized by subjects, could possibly be used instead of the visual indicator used so far in our experiments and by Mou et al. (2009).

Experiment 6

Since we have found, so far, in the previous experiments that the external visual indicator has shown no effect, we investigated whether another form of an indicator of reference direction, an indicator present in the scene throughout the experiment, could be effective. For the current experiment, we investigated the use of alignment of the orientation of the objects as a cue for reference direction. This cue would be part of the layout of objects and would be more salient and less intrusive than the visual indicator and it would be present during both learning and testing. Rather than have the objects in random orientation as before, we aligned their orientations to point all in one direction. The objects' orientation now acted as an internal cue to reference direction. This is in comparison to the chopstick which is considered external as it is added to the scene afterwards and must be used in addition to subjects' internal representations of the objects. With this change in experimental setup, the subject and table rotation conditions were tested in this experiment. In addition, two orientations were tested, one aligned with the learning perspective and one aligned with the testing perspective.

When taking into account the theories of Simons and Wang (1998) and Mou et al. (2009), Simons and Wang (1998) would argue that object alignment should have no effect, as body-based information is more important and efficient to use. Conditions dealing with different object alignment (where the objects are pointing), should make no difference. Once again, body locomotion should lead to a better performance (accuracy and reaction time) than scene rotation. Mou et al. (2009) would give the opposite prediction. They would argue that the orientation cue should have an effect, as it can be used as a source of reference direction. In addition, if the objects are aligned with observers' egocentric perspective (termed 0 degrees), the performance would be better than that in a condition where the orientation was 50 degrees (which is harder to use as a reference direction).

We hypothesized then, following Mou et al.'s (2009) theory, that by using orientation as an internal reference cue, subjects would perform comparably well on both table rotation and subject rotation conditions. Also, with all else being equal (i.e. no movement at all), subjects were likely to perform better on tasks where the objects were pointing directly towards them (0 degrees), then when they were pointing away from them (50 degrees).

Methods

Subjects

For this experiment, 24 subjects (5 males, 19 females), all undergraduate students from McMaster University, were tested ranging from 18-29 years of age (M = 19.29, SD = 2.53), and all participated for one course credit.

Materials and Design

The setup for the sixth experiment was essentially the same as the second experiment, the only difference being the conditions and the elimination of the visual indicator (chopstick). Subjects, once again, were able to see some of the events occurring during the retention phase, as they could see themselves or the table move while it was covered with cardboard. The objects, while arranged in random locations, were placed on the table pointing to a direction in the same way the visual indicator was used. At the beginning of a trial, before the subject viewed the layout of the objects, the experimenter placed each of the objects so that the long axis of the object would be pointing towards a given direction based on the condition given. This setup was different from all previous experiments where each object was placed in a random orientation. For this experiment, all the objects were essentially parallel to each other after the layout was complete, since they were all pointing in the same direction. For three of the four conditions, the objects were placed at 0 degrees, meaning when the subjects viewed the layout, all the objects were pointing towards them at the starting position. For the other condition, the objects were placed so that they were pointing 50 degrees to the right away from the subject and the origin or study viewpoint.

The four conditions that all subjects went through were: having the objects placed at 0 degrees with no movement of either table or subjects (NRI), having the objects placed at 50 degrees to the right with no movement (NRI-50), having the objects placed at 0 degrees and then having the table move 50 degrees to the right (TRI), having the objects placed at 0 degrees and then having the subject move 50 degrees to the right (SRI) (see Table 6 and Figure 16 for layout of conditions) . It should be noted that for two of the conditions, no movement from the subject or table was involved. Those two conditions were essentially used as control conditions and to test the effects of orientation directly.

Table 6 - Experiment 6 Conditions

Condition	Table at test	Observer at test	Object alignment at learning
NRI	0	0	0
NRI-50	0	0	50 degrees
TRI	50 rotation	0	0
SRI	0	50 walk	0

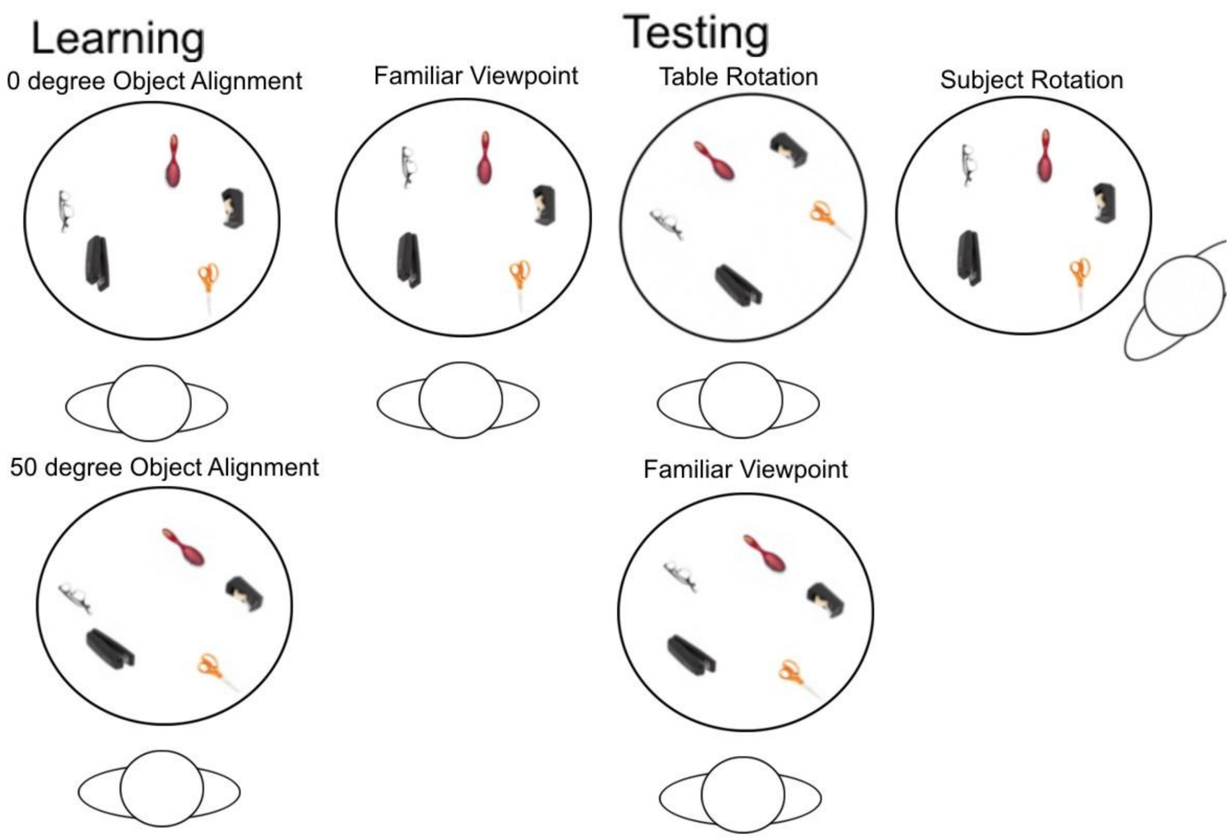

Figure 16 – Experiment 6 Conditions

Results

Paired, one-tailed t-tests revealed no significant differences in accuracy between the two familiar viewpoint conditions (NRI and NRI-50) [$t(23) = 0.569$, $p = 0.287$], suggesting the orientation of the objects themselves does not have an effect on spatial memory. No difference between the two rotation conditions (TRI and SRI) [$t(23) = 0.407$, $p = 0.344$] was found, suggesting the performance of table rotation improved to the extent of walking. The comparison of NRI and SRI [$t(23) = 5.23$, $p < 0.001$] was significant, suggesting there is a cost of viewpoint change (see Figure 17).

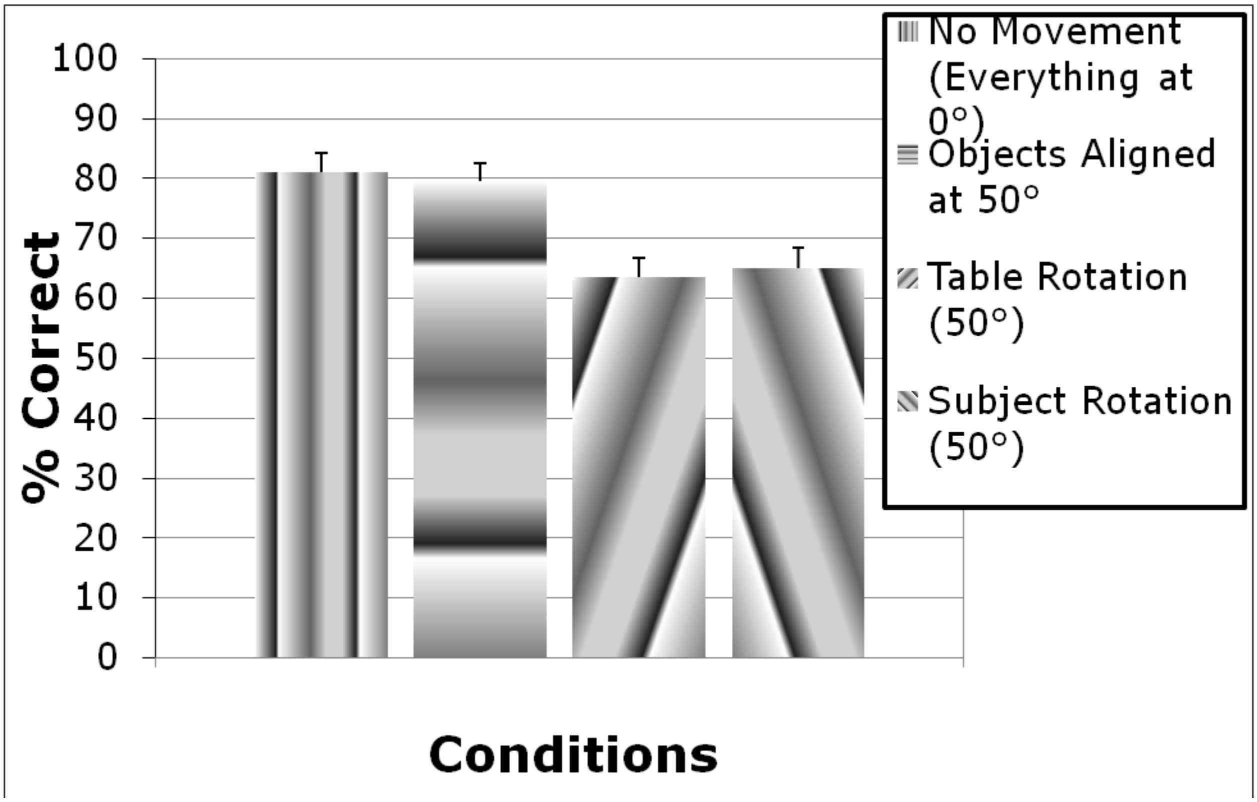

Figure 17 – Accuracy in detecting position change as the function of table or subject rotation and object alignment

For RT, paired t-tests revealed significant differences in reaction time on correct trials in the two familiar viewpoint conditions (TRI and SRI) [$t(23) = 2.04$, $p < 0.05$], suggesting objects aligned at 50 degrees may have been more difficult for subjects. No difference between the two rotation conditions (TRI and SRI) [$t(23) = 0.450$, $p = 0.329$] were found, again suggesting the performance of table rotation improved to the extent of walking. The comparison of NRI and SRI [$t(23) = 4.67$, $p < 0.001$] was significant, again suggesting there is a cost of viewpoint change (see Figure 18).

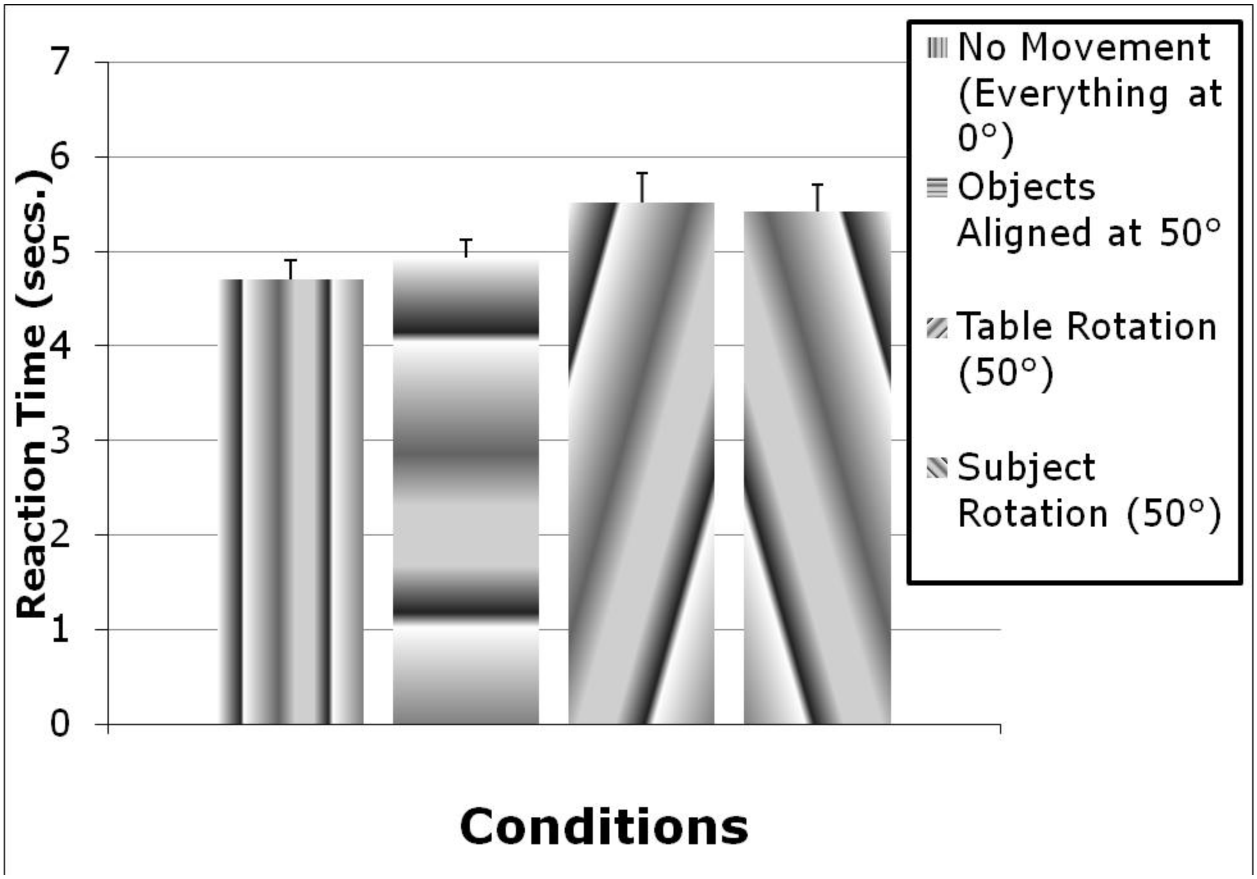

Figure 18 – Reaction time (correct trials) in detecting position change as the function of table or subject rotation and object alignment

Discussion

We had hypothesized that by using orientation as an internal reference cue, subjects would perform comparably well on both table rotation and subject rotation conditions. Also, subjects were likely to perform better on tasks where the objects were pointing directly towards them (0 degrees), than when they were pointing away from them (50 degrees). This closely follows Mou et al.'s (2009) theory. Simons and Wang's (1998) theory predicted the opposite, and argued that object alignment should have no effect and that subject rotation should still lead to greater performance.

The results strongly supported Mou et al.'s (2009) idea about the reference direction. What we found in this experiment has not been found in our previous 5 experiments using the chopstick as an external visual indicator. Subjects had accuracy and reaction times that were comparable in both the table rotation and subject rotation conditions. Thus, this was the only experiment we ran so far that supported Mou et al.'s (2009) ideas in some form, yet it did not involve the use of the external visual indicator. The reason for these findings is likely due to the fact that the reference direction cue was now internalised through the use of an orientation cue. As mentioned in previous experiments, subjects might have had a difficult time internalizing the external visual indicator as a reference cue, because it was something external that was introduced after they had already internalized the visual layout of the objects in the learning phase, and thus it could have acted as more of a distracter than as a tool to be used. By having a reference cue that was a part of the visual layout and that was present throughout the experiment, subjects were then able to utilize the object alignment as a cue of reference direction.

In this experiment, the orientation cue was comparable to a set of intrinsic axes (Burgess, 2006, 2008; Greenauer & Waller, 2008; Holmes & Sholl, 2005; Kelly & McNamara, 2008; Mou, Liu, et al., 2009; Mou et al., 2006; Mou, McNamara, et al., 2004; Mou & McNamara, 2002; Mou, Xiao, et al., 2008; Shelton & McNamara, 2001; Vidal, Lehmann, & Bülthoff, 2009; Wraga et al., 2004). While the objects were not placed in organized rows as in these other studies, the objects' orientation were nonetheless, aligned with each other as they were pointing in a uniform direction. This would have given the object layout a crude, yet still effective, set of intrinsic axes, thus making it easier for subjects to encode the visual layout. Even after a viewpoint shift, subjects were still able to efficiently recall the original layout from memory, due to memorizing the objects along a set of axes. The fact that there was no difference in performance between the subject rotation and table rotation conditions, and that intrinsic axes were involved, points out that perhaps subjects were encoding the layout from an allocentric frame of reference. As mentioned in the studies, the intrinsic axes make it easier for subjects to encode allocentrically, as the objects can be encoded in clusters. Each cluster would pertain to a single, vertical axis.

As expected, subjects were much more accurate in conditions with no movement (no viewpoint shift) (NRI) than conditions with subject movement (SRI). This is due to the fact that it is easier to memorize a spatial layout when everything is kept stationary, thus even with subject locomotion, a viewpoint cost still occurs.

The differentiation of orientation with egocentric direction had no effect on accuracy but an effect on reaction time. By differentiation, we mean the change in degree alignment. The effect of orientation itself, in that all objects are in the same orientation pointing to one direction, had a strong effect as seen in the comparable performance of table and subject rotation. Going back to differentiation of alignment, this means that subjects were still roughly as accurate when the objects were pointing 50 degrees away as they were when the objects were pointing at 0 degrees (at the subjects). However, reaction time was affected, as subjects were slower to respond in the 50 degree object alignment condition than in the 0 degree object alignment condition. It can be argued that the objects could be pointing to a direction further away from the starting position, and subjects would still be able to be just as accurate, since the objects are all pointing towards the same direction and are parallel to each other in one alignment (and thus easier to memorize). This however, may cause an increase in reaction time, as subjects will have to spend more time processing the layout of objects pointing away from them (and their egocentric viewpoint).

Memorizing objects in one alignment, as compared to random orientation as seen in the previous experiments, seems to have been easier for subjects, based on accuracy and reaction times, and we will address this issue further, as we will do comparisons between experiments to see how much better performance was in this experiment. Overall, accuracy seems to be higher across all conditions, as well as reaction times being shorter, when compared to the previous experiments. This is likely due to the fact that subjects could memorize the objects almost as elongated figures pointing in one direction along an axis, compared to taking note of where each individual object was pointing. In essence, having the objects in a uniform alignment eliminated some feature cues of the objects, thus making memorization a little easier and efficient for subjects.

Experiment 2 & 6 Comparison

To see how effective the object alignment was over the random orientation of objects seen in previous experiments, we decided to compare the results for each condition from Experiment 2 with the table and subject rotation conditions from Experiment 6. Experiment 2 was selected since it had the most similar experimental setup as Experiment 6, which included subjects being able to move themselves and seeing the table move during the retention phase. We were also able to do comparisons of the conditions from Experiment 6 with the conditions from Experiment 2 with and without the visual indicator (chopstick), and once again see the effect (or lack of) the visual indicator provided. This also gave us an idea of how effective an internal cue (the object alignment) was over an external cue (the visual indicator), regarding its role as a reference direction cue.

Results

Unequal variance, two-tailed t-tests were used to compare each condition from Experiment 2 with the table and subject rotation conditions from Experiment 6. Regarding accuracy, the comparisons with the subject rotations conditions from Experiment 2 and the conditions from Experiment 6 all proved to be not significant, those being: the subject rotation without chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(29.42) = 0.071$, $p = 0.944$], the subject rotation without chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(31.14) = 0.311$, $p = 0.758$], the subject rotation with chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(29.01) = 0.733$, $p = 0.470$], and the subject rotation with chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(30.71) = 0.954$, $p = 0.348$].

The comparisons with the table rotations conditions from Experiment 2 and the conditions from Experiment 6 all proved to be statistically significant, those being: the table rotation without chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(27.94) = 3.04$, $p < 0.01$], the table rotation without chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(29.57) = 3.20$, $p < 0.01$], the table rotation with chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(32.85) = 2.94$, $p < 0.01$], and the table rotation with chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(34.55) = 3.13$, $p < 0.01$]. When comparing the two experiments, accuracy was only significantly different between the two when the table rotation conditions from Experiment 2 were involved. No difference was observed when looking at the comparisons involving the subject rotation conditions from Experiment 2.

Regarding correct reaction time, all applicable comparisons between the two experiments were found to be statistically significant. The comparisons with the subject rotations conditions from Experiment 2 and the conditions from Experiment 6, were: the subject rotation without chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(36.71) = 2.28$, $p < 0.05$], the subject rotation without chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(35.71) = 2.56$, $p < 0.05$], the subject rotation with chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(38.74) = 3.20$, $p < 0.01$], and the subject rotation with chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(38.28) = 3.54$, $p < 0.01$].

The comparisons with the table rotations conditions from Experiment 2 and the conditions from Experiment 6, were: the table rotation without chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(30.05) = 4.14$, $p < 0.001$], the table rotation without chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(28.88) = 4.39$, $p < 0.001$], the table rotation with chopstick condition (Experiment 2) and the table rotation condition (Experiment 6) [$t(34.37) = 5.32$, $p < 0.001$], and the table rotation with chopstick condition (Experiment 2) and the subject rotation condition (Experiment 6) [$t(33.17) = 5.64$, $p < 0.001$]. When comparing the two experiments, reaction time was significantly different between the two regardless if the table rotation or subject rotation conditions were involved.

Discussion

When looking at the results, it is clear that the object orientation acting as an internal cue of reference direction was much more effective than the visual indicator in getting performance to be comparable between the table and subject rotation conditions. When doing the comparisons, comparing the conditions from Experiment 2 with or without the visual indicator, ended with the same results as performance was similar.

When the table and subject rotation conditions from Experiment 6 were compared with the table rotation conditions from Experiment 2, there was a significant difference. It can be concluded here that with the switch from the visual indicator and random orientation of objects from Experiment 2 to the object alignment in Experiment 6, subjects performed much more accurately and responded faster in the table rotation conditions in Experiment 6. For table rotation, in Experiment 2, subjects scored 48.0% and 44.9% in accuracy (with and without a visual indicator, respectively), while in Experiment 6, subjects scored 63.6%. We can see here that clearly the object alignment as an internal cue greatly improved performance in the table rotation tasks and made it comparably accurate as the subject rotation task (65.0% in Experiment 6). In Experiment 2 in the table rotation conditions, subjects had reaction times of 8.02 and 7.71 seconds (with and without a visual indicator, respectively), while in Experiment 6, subjects had a reaction time of 5.52 seconds.

As mentioned earlier, part of the reason for the increase in performance is that the internal cue (object alignment) is part of the scene, along salient intrinsic axes, and is present throughout the experiment. This is unlike the visual indicator, which was introduced only during the test phase as a novel external cue. It should be noted that had the visual indicator been present throughout both study and test phases, it would not really be classified as an external cue, since it would be present the whole time in the spatial layout of the objects and be a part of the scene (more internal). The internal cue is simply the objects present during the experiment, and any or all of them takes the place of the visual indicator acting as a reference cue.

The other reason for why subjects may have done better in the table rotation conditions in Experiment 6 compared to Experiment 2, is that because the objects are acting as internal cues, they must all be aligned in a uniform direction. This replaces the random orientation of objects found in previous experiments. In doing so, all objects are all pointing in the same direction and are parallel to each other. This eliminates some feature cues of the objects, as subjects no longer have to take into consideration where each object is pointing, or the orientation of each object. It can be argued, though, that this may not have even been an issue with subjects in previous experiments, since they only had five seconds to memorize the layout of objects, and thus there would have been no time to take note of the objects' orientation. It could be speculated that in Experiment 6, subjects would have memorized the layout of objects as featureless figures pointing in one direction. This would be easier than memorizing the layout of objects pointing in individual directions. Regardless of how the internal cue of object alignment benefited subjects, the main point is it is a benefit. Clearly the source of information provided by the internal cue as reference direction was a suitable alternative to body-based information, since subjects had comparable accuracy throughout. The object alignment may have even made the experimental task easier, as subjects were much faster and more accurate in comparison to Experiment 2.

When the applicable conditions from Experiment 6 were compared with the subject rotation conditions from Experiment 2, there was no significant difference. It can be concluded that even with the switch from the visual indicator and random orientation of objects from Experiment 2 to the object alignment in Experiment 6, subjects still performed comparably the same in the subject rotation conditions. From Experiment 2, subjects scored 59.2% and 63.1% in accuracy (with and without a visual indicator, respectively), while in Experiment 6, subjects scored 65%. We can see here that the body-based information used in these conditions is effective and the primary source of information to be used by subjects in the change detection task if available (and reliable). We can assume that even with the internal reference cue of object alignment present in Experiment 6, subjects were likely to have used the body-based information, since accuracy was roughly comparable in both experiments. If the internal reference cue had additive effects or benefits, we would have seen higher accuracy in Experiment 6 regarding subject rotation. Thus it appears only one source of information may have been used.

It should be noted that while object alignment had no effect on subject rotation accuracy, there was still an effect regarding reaction time, where subjects responded faster in Experiment 6. In Experiment 2 in the subject rotation conditions, subjects had reaction times of 6.82 and 6.52 seconds (with and without a visual indicator, respectively), while in Experiment 6, subjects had a reaction time of 5.42 seconds. Even though accuracy was comparable, it is possible that subjects in Experiment 6 found the task easier with the object alignment, and thus were able to give a response sooner, than those subjects in Experiment 2. While it is hard to determine for sure whether subjects were still using only body-based cues, or switched to strictly relying on object alignment, we can conclude that both lead to equivalent accuracy, given the results. It is possible that both sources are not exactly redundant and a source of conflict, like body-based cues and the visual indicator, but rather the object alignment would have allowed subjects to encode allocentrically, and in turn subjects would still rely on their body-based cues after movement, to help determine how far the scene shifted. Also, another key factor is that subjects in Experiment 6 likely found the table rotation task to be of the same difficulty as the subject rotation task, as the reaction times were comparable.

When taking everything into account, it can be concluded that the object alignment as an internal cue, found in Experiment 6, increased accuracy (at least for the table rotation conditions), and possibly made the change detection task easier, as subjects were responding faster on both table and subject rotation conditions in comparison to Experiment 2. Subjects were now able to respond just as accurately in table rotation conditions in comparison to subject rotation conditions, but also to find both conditions of comparable difficulty. Object alignment proved to be a good alternative source of reference direction information as the body-based information gathered in the subject rotation conditions. While, there may be a preference to use the body-based information in the subject rotation conditions, it cannot be denied that the switch from random object orientation to object alignment decreased reaction time, and possibly ease of task.

General Discussion

Body-based cues have been found to be advantageous over an external reference direction cue, in maintaining spatial recognition performance. Thus, in our opinion based on the results collected in our study, it appears that there is more support towards Simons and Wang (1998) regarding the effects of observer locomotion and the added benefit of 'extra-retinal' information. From Experiments 1-5, performance had been the strongest in conditions involving normal observer locomotion (excluding the control condition in Experiment 1), and this is largely due to automatic spatial updating that occurs during movement (i.e. Burgess, 2008; de Vega & Rodrigo, 2001; Farrell & Robertson, 1998; Klatzky et al., 1998; Mou, Li, et al., 2008; Presson & Montello, 1994; Vidal et al., 2009; Wraga et al., 2004; Yardley & Higgins, 1998). Thus, while subjects were being rotated, they were able to mentally update what the layout should look like from their new viewpoint. Thus when presented with the layout during the test phase, subjects were already prepared. This process cannot occur while subjects remain stationary, thus they have the disadvantage of not being able to mentally update their scene. We tested whether seeing a covered table rotate would allow stationary subjects to mentally update a rotating scene, however performance was largely unaffected.

In all the experiments (1-5) that involved the use of the visual indicator as a reference direction cue, not one was benefited by its presence. Thus we failed to replicate Mou et al.'s (2009) results in finding an enhancement in the performance of table rotation tasks when the visual indicator was present. We also introduced the visual indicator to conditions where body-based information was unreliable (disorientation and indirect walking), but again no change in performance was found.

When we did find support for Mou et al.'s (2009) ideas, it was not from the use of the visual indicator, but rather from the use of a cue that was more salient and intrinsic to the structure of the layout itself, that being object alignment. What was different with this cue, was that it allowed for the use of intrinsic axes, that were more readily encoded and identified by subjects (Burgess, 2006, 2008; Greenauer & Waller, 2008; Holmes & Sholl, 2005; Kelly & McNamara, 2008; Mou, Liu, et al., 2009; Mou et al., 2006; Mou, McNamara, et al., 2004; Mou & McNamara, 2002; Mou, Xiao, et al., 2008; Shelton & McNamara, 2001; Vidal, Lehmann, & Bülthoff, 2009; Wraga et al., 2004). All the objects were now aligned and pointing to one direction, thus setting up separate axes that objects might be situated on. Since subjects were able to encode this cue as part of their mental layout, it resulted in equivalent performance (accuracy and reaction time) between the subject and table rotation conditions. It should be noted that these results were only found when we removed an external landmark cue and instead altered the layout of objects to be in uniform alignment (which acted as an intrinsic cue). The problem with this is that it made the experiment more 'artificial.' If subjects were only able to decrease the cost of viewpoint shift after the objects in a layout were placed in one alignment, then this severely limits the applicability these findings have in the real world. In real world environments, observers will come across situations where objects are scattered all over and in a variety of orientations. Very infrequently will observers come across situations where everything in their field of vision will be in the same orientation, all in one alignment. Some examples may be shopping aisles where grocery items are placed in lines facing shoppers, or a classroom where desks and chairs are all aligned in rows. Even the concept of intrinsic axes can be limited, as this theory assumes that what we see in our visual environment can be placed along separated axes, and that we can encode objects in clusters based on what axis they lie on. This can be possible along a larger scale, such as encoding a large area with grid street patterns by viewing a map, but this can be difficult in our immediate, small scale visual surroundings. In many of the intrinsic axes studies, subjects had high performance, simply because the layout they studied had objects aligned in rows and columns. Having a random orientation of objects, like in Experiments 1-5, is more natural in that observers are likely to find objects scattered randomly across their field of vision. The fact that we were only able to obtain a decrease in viewpoint shift in conditions where the scene shifted after using intrinsic axes (object alignment), demonstrates the limitation of having scene locomotion become equivalent in spatial recognition performance to that of observer locomotion.

In some studies (Greenauer & Waller, 2008; Holmes & Sholl, 2005; Mou, Li, et al., 2008; Mou, Liu, et al., 2009; Mou & McNamara, 2002; Mou, Biocca, et al., 2004; Roskos-Ewoldsen et al., 1998; Sholl, 1999), instructional cues allowed subjects to increase their spatial recognition performance. Based on these findings and to avoid any ambiguity that subjects may form during the task, we would tell subjects how far they would travel (50 degrees), and would show them the exact spot they would move to during the subject rotation tasks. As for the visual indicator, we made it clear what its purpose was, by telling subjects that it would point towards the original viewpoint subjects were at from the very start. Telling subjects at the beginning where they were to be moved to would not have made a difference in performance as subjects were only to be moved to one spot for every subject rotation task. Also, despite informing subjects of the visual indicator's use, it is clear based on the results, that this made no difference. Perhaps if more detailed instructions were given, such as strategies subjects could use to encode the visual layout, we would see an increase in performance in the table rotation and altered subject rotation conditions.

When we take the experimental results into consideration, we can infer whether subjects were encoding the experimental layout from an egocentric or allocentric frame of reference. In Experiments 1-5, since there was a difference in performance between subject rotation and table rotation or altered subject rotation, we may infer that subjects were encoding the scene egocentrically. This would explain why the cost of viewpoint shift was lower when subjects rotated, but remained relatively high when the table rotated. If the scene was encoded egocentrically, subjects would have had more difficulty in recognizing the scene after it rotated. In Experiment 6, as we introduced crude intrinsic axes by having uniform object alignment, we found no difference in performance between subject rotation and table rotation. We may infer that subjects were encoding the scene allocentrically, as they would have been able to encode the objects along aligned rows, and thus be better able to recall the scene after the table rotated. This frame of reference would result in there being no difference between conditions, as we have found.

Our experiments have some limitations that were mentioned in the individual experimental discussion sections, but some main limitations overall, are using the same degree of viewpoint change (50 degrees), using only active movement, and using a strictly novel environment. A number of studies (i.e. Biederman & Gerhardstein, 1993; de Vega & Rodrigo, 2001; Diwadkar & McNamara, 1997; Farrell & Robertson, 1998; Finlay et al., 2007; Kelly & McNamara, 2008; Kelly et al., 2008; Mou, McNamara, et al., 2004; Mou, Biocca, et al., 2004; Roskos-Ewoldsen et al., 1998; Wang & Simons, 1999; Yardley & Higgins, 1998) have pointed out that performance decreases the greater the angular distance is from the original viewpoint to the new viewpoint. What we have found only refers to a small angular distance (50 degrees). One distance was used to have consistency amongst all experiments, but it is possible that if we used larger angular distances, we would find low performance in both table rotation and subject rotation conditions, and thus find no significant effect for observer locomotion. Mou et al. (2009) found in one of their experiments, to be no difference in performance between novel viewpoint conditions when a 98 degree angular distance was used. We only used active movement, but results may have been different if we also explored passive movement. The indirect walking condition in Experiments 3 and 5, were somewhat close to a passive movement, as subjects moved but received insufficient body-based information. Based on the studies in this research area (Christou & Bülthoff, 1999; Coluccia et al., 2007; Klatzky et al., 1998; Simons et al., 2002; Sun, Campos, Young, et al., 2004; Sun, Chan, et al., 2004; Wang & Simons, 1999; Wraga et al., 2004; Yardley & Higgins, 1998), it may be safe to assume that if a passive movement allowed for a subject to be moved towards the new viewpoint, like in a wheelchair, performance would not differ greatly, if at all, but if a method such as having subjects passively view an experimenter move around the scene, was employed, subjects would likely have low performance in these conditions as they would have to imagine their own movements based on someone else's (the experimenter's). If a familiar environment was used instead of the novel one in the experiments, results would have been different, mainly there would be more viewpoint-independent performance. If subjects were to be tested in a familiar environment, body-based information may not be that advantageous, simply because subjects would have a mental map of the environment that they would be able to retrieve from long term memory if needed, and thus viewpoint shift, and whether the observer or scene moved, would not affect performance. However, most experiments use novel environments simply because using a familiar one is not as plausible, as the environment would have to be one that is familiar to all subjects (like a university campus), or extra sessions must be done before the actual experiment to get subjects familiar with the test environment. Also, this would make the experiment more 'artificial' since in the real world, observers will come across environments that are novel to them quite frequently.

While we have our own limitations to consider, we must also mention some limitations of Mou et al. (2009) and why we were unsuccessful in replicating their findings. There was some difference in the methods of the two experiments. Mou et al. (2009) tested between-groups (subjects only did a pair of conditions out of four, those being familiar or novel), while we tested within-groups. Also, where in our experiments we had objects that were visible in a dim light on a table, Mou et al. (2009) did not use a projector and instead used florescent painted objects. Thus subjects in their experiment would only see the objects and nothing else, not even the table surface. While this eliminates all features that are not the objects, the main concern is, as mentioned before, this makes the experiment more 'artificial' and thus limits the applicability to real world environments. In a real visual environment, there are many feature cues present along with visible objects, and in order to recognize changes in scene, observers may take note of not only the objects present but any feature cues present that are associated with the objects. While eliminating feature cues allows for more experimental control, it takes away applicability, thus it may not be wise to eliminate all feature cues in the experiment. Very rarely, if at all, will subjects come across environments where only the objects are present, and all feature cues of the environment, such as edges of surrounding walls, are eliminated. Thus we have very minimum feature cues in our experiments. The only things present in our experiments besides the objects are the table the objects are situated on and the surrounding edgeless (circular) walls of the test room.

Conclusion

Unlike what was found by Mou et al. (2009), locomotion still produces a significant benefit even when a visual indicator was available to indicate spatial reference directions. This is due to observer locomotion causing automatic spatial updating to occur. As the experiments demonstrate, the visual indicator does not appear to have a significant effect on performance in the change detection paradigm, at least when the viewpoint shift is no more than 50 degrees. Only when intrinsic cues were used instead of an external visual indicator, did we find no significant difference in spatial recognition performance between observer and scene locomotion, suggesting the contribution of the reference direction in the scene.

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