Running head: EFFORT, INTENTION, AND DISTANCE PERCEPTION

Effects of Effort and Intention on Distance Perception:

What Happens When You Change Your Mind?

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Abstract

People perceive their environment in terms of the energetic costs associated with the actions that they intend to perform. For example, hills look steeper when people wear a heavy backpack (Bhalla and Proffitt 1999) and targets look farther away when people throw heavy balls to them (Witt et al 2004). Moreover, these effects are conditionalized by intention. Only effort associated with an intended action influences perception (Witt et al 2004). These experiments demonstrate that non-visual information -- such as the energy expenditure required to perform an intended action -- influences perception. Several implications result from this research including the claim that perception is not a modular, informationally-encapsulated process. This research is often met with resistance and an alternative explanation that the effects are due to post-perceptual processes as opposed to an effect on perception itself. In a critical experiment, we examined the locus of these effects and demonstrated that effort and intention affect perception directly rather than influencing post-perceptual processes. Perception relates spatial layout, as specified by optical and ocular-motor information, to the energetic costs of intended actions.

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For over 100 years, researchers have attempted to delineate the information involved in distance perception, and in so doing, have focused primarily on optical and ocular-motor information (see, e.g., Cutting and Vishton 1995; Proffitt and Caudek 2002). However, recent research in our lab suggests that perceived distance is also influenced by the effort associated with intended actions. For example, targets appeared farther away when participants wore heavy backpacks (Proffitt et al 2003) or when they threw heavy as opposed to light balls to target locations (Witt et al 2004). Moreover, only effort for the intended action was found to influence perception (Witt et al 2004). After throwing heavy balls, targets looked farther away to participants who intended to throw again but not to those who intended to walk to the targets.

These findings have significant implications for understanding the nature of perception. Supposing that these effects are truly perceptual in nature, then perception cannot be construed to be an informationally-encapsulated, modular process, as has often been suggested. On the other hand, if the effects of effort and intention were found to occur post-perceptually, then these findings would have quite different implications. The current experiments assessed when in the perception /action process these influences have their effect.

The effort required to perform an action has been shown to affect the perception of two aspects of spatial layout, slant and distance, as assessed using verbal reports and perceptual matching tasks. Both perceived slant and perceived distance increased when more effort was required to act on the environment. For example, perceived slant increased with wearing a heavy load or after completing a long run (Bhalla and Proffitt 1999; Proffitt et al 1995). Hills also looked steeper to participants with low fitness levels and elderly participants, especially those with declining health (Bhalla and Proffitt 1999). Similarly, perceived distance increased with wearing a heavy load (Proffitt et al 2003) and after throwing a heavy ball (Witt et al 2004). In addition, targets looked farther away when they were placed up a steep hill, which would be effortful to ascend (Stefanucci et al 2005).

In other studies, we increased anticipated effort for walking by inducing a visuomotor adaptation (Proffitt et al 2003; Witt et al 2004). Participants walked on a treadmill, so although they exerted energy to walk forward, vision provided continuous information that they were not going anywhere. This induced a recalibration in the relationship between walking energy and expected perceptual outcome such that participants learned that they would have to expend some walking energy to go nowhere, and consequently, more energy to walk a prescribed distance. In one experiment, participants walked on a treadmill while viewing a virtual world through a head-mounted display (HMD). One group of participants viewed a stationary world, so they recalibrated to the new relationship between energy expenditure and perceptual outcome. Another group of participants viewed a world moving at canonical speed, that is, at the same pace as they were walking, so they did not undergo adaptation. After walking on the treadmill, the adapted group perceived targets to be farther away relative to the canonical optic flow group as measured with verbal reports (Proffitt et al 2003). The adapted group learned that it would take more energy to walk the prescribed distance and so perceived the distance to be farther.

However, effort for walking only influences perceived distance when participants intend to walk to the target (Witt et al 2004). Using a similar treadmill manipulation, we increased anticipated effort for walking by having participants walk on a treadmill with zero optic flow. They did not wear the virtual reality HMD, instead participants viewed a stationary room and recalibrated to learn that it took walking energy to go nowhere. Prior to walking on the treadmill, participants verbally estimated the distance to targets in a hallway. After each estimate, one group of participants closed their eyes and walked to the target, so for each target, they viewed the target with the intention to walk. Another group of participants threw a small beanbag at the target, so this group viewed each target with the intention to throw. After walking on the treadmill, both groups were told they would perform the same task as they had prior to walking on the treadmill. The *walkers* would estimate the distance and then blindwalk to the target while the *throwers* would estimate the distance and then throw to the target. We found that participants who intended to walk perceived the targets to be farther away relative to participants who intended to throw. Effort for walking influenced participants who intended to walk but not participants who intended to throw.

What would happen, however, if after looking at the post-adaptation target, the *throwers* were told to close their eyes and then told to walk to the target instead? They had previously seen the target to be closer than the *walkers* since they intended to throw rather than walk to it, yet they had also undergone the effort-for-walking manipulation. Will they update the remembered distance to the target to take into account effort for walking now that they intend to walk? Answering this question allows us to get at *when* the effects of effort exert their influence in the perception/action cycle. If the effects are purely perceptual, then effort can only exert its influence when perceivers view the target, so the *throwers-turn-walkers* should still maintain their perception of the target being closer. However, if effort exerts its influence on a post-perceptual process, then the *throwers-turn-walkers* should update their representation of the target to be farther away since it would take more effort to walk to the target.

The purpose of the current experiment was to provide evidence supporting one or the other of these two alternatives by investigating when effort and intention exert their effects. If their influence does not occur during perception, but rather, during the planning and execution of the response, then perception may well be immutable to such non-visual influences. But if the effects are truly perceptual, then these findings challenge those theories of the perception of spatial layout that contend that perception is solely a function of optical and ocular-motor information.

Overview

To address the question of when effort and intention exert their influence, we separated the time when the participants viewed the target from the time that they planned and executed their response. Between these two times, we changed the participants' intentions to act for one group of participants. Initially, we told one group of participants that they would blindwalk and another group that they would blind throw to a target. Both groups walked on a treadmill and experienced stationary optic flow, and then viewed a target in the hallway. After putting on the blindfold, we told the *throwers* that we had erred in our prior instructions and that we wanted them to blindwalk to the target instead. Thus, both groups blindwalked to the target, but only the *walkers* viewed the target with the intention to walk; the *throwers* viewed the target with the intention to throw. The *walkers* should blindwalk past the target because effort for walking increased and they intended to walk to the target (Witt et al 2004). The critical question is whether the *throwers* will also walk too far. If effort and intention exert their effects post-perceptually, then the *throwers* should walk just as far as the *walkers* since both groups underwent the same effort manipulation and performed the same action. In contrast, if the influence of effort and intention occurs during perception, then the *throwers* should only walk as far as they perceived the target to be, which, based on our previous findings, should be shorter than for the *walkers*. The timeline for the experiment is depicted in figure 1.

Experiment 1: Changing the Intention

To determine when effort and intention exert their effects, we divided participants into two groups: *throwers* and *walkers*. Both groups walked on a treadmill with stationary optic flow and then viewed a target in a hallway. The *walkers* viewed the target with the intention to walk, and consequently donned a blindfold and blindwalked to the target. The *throwers* viewed the target with the intention to throw, but after putting the blindfold, we instructed them to blindwalk to the target instead.

Method

Subjects. Twenty-four volunteers (12 male, 12 female) participated in the experiment in exchange for credit for a psychology course or for financial compensation. All gave informed consent.

Materials and stimuli. Participants walked on a motorized treadmill (Precor 9.1). A small blindfold occluded vision during blindwalking. We put duct tape in the shape of an 'x' on the floor to mark a target at 8m. A small beanbag was shown to the *throwers* as the object to be thrown.

Procedure. Participants were assigned to one of two groups: *walkers* or *throwers*. The only difference between the two groups was the initial instruction of the experiment. The *walkers* were told that they would walk on a treadmill for a few minutes and then blindwalk to a target in the hallway. The *throwers* were told that they would walk on a treadmill and then blind throw to a target in the hallway. After these initial instructions, both groups walked on the treadmill with their eyes open for 3 minutes at 3 mph. Participants closed their eyes before the experimenter stopped the treadmill and were led into the hallway where they viewed a target placed 8m away. As a result of the initial instructions, the *walkers* viewed the target with the intention to walk while the *throwers* anticipated throwing to the target. Both groups put the blindfold back on, and the *throwers* were told to walk to the target instead of throwing. They were not given a second chance to look at the target. The experimenter followed closely behind all participants to prevent them from walking into the walls.

Results and Discussion

We ran a 2 (intention) x 2 (sex) ANOVA with blindwalked distance as the dependent measure. The effect of intention on blindwalked distance was significant ($F(1,20) = 4.265$, $p = .05$, $d = 0.18$). The *walkers* blindwalked farther than the *throwers* (see figure 2). This finding suggests that the effects of effort and intention occur during perception and not during post-perceptual processes that are involved in generating and executing responses. Neither sex ($F(1,20) = 2.64$, $p > .10$) nor the interaction between sex and intention ($F(1,20) = 1.43$, $p > .20$) was significant.

The *walkers* blindwalked past the target, as predicted. However, the *throwers* walked short of the target. One possible explanation for this group's response is that they may have felt uncomfortable being told to walk after putting on the blindfold. This possibility is tested in experiment 2. However, another possible explanation is that the *throwers* perceived the target to be closer after walking on the treadmill. Indeed, this is consistent with previous experiments that have used the treadmill to manipulate perceived distance. In Proffitt et al (2003), the group that had canonical optic flow verbally reported the target to be closer after walking on the treadmill, and in Witt et al (2004), the group that intended to throw verbally reported the target to be closer after walking on the treadmill (see figure 3). We have tentatively interpreted these effects of foreshortening as a warm-up effect: participants increased their aerobic potential by walking on the treadmill at a brisk pace thereby making it easier to physically act upon the specified extent, so the target looks closer. A more direct test of this account is currently underway in our laboratory.

Experiment 2: Without the Treadmill

In the previous experiment, we manipulated intention by giving the groups different instructions. We found that the *throwers* walked short of the target, which is consistent with previous findings using verbal estimates (Proffitt et al 2003; Witt et al 2004). However, it is possible that this group was more uncomfortable walking since they were not prepared to walk, which may be why they walked too short. In experiment 2, we controlled for this by using the same intention manipulation but without the effort for walking manipulation. Therefore, both groups should perceive the target to be in the same place, so if just changing the intention in and of itself affects blindwalked distance, we should see a difference in blindwalked distance between the two groups when there is no effort manipulation.

Method

Subjects. Twenty-four volunteers (12 male, 12 female) participated in the experiment in exchange for payment or for course credit. All gave informed consent.

Materials and stimuli. The materials and stimuli were the same as in experiment 1 except that we did not use the treadmill.

Procedure. As in experiment 1, different instructions were given to two groups. One group was told they would view a target, put on a blindfold, and walk to the target. Another group was told they would view a target, put on a blindfold, and throw to the target. Both groups were blindfolded and led into the hall, viewed a target at 8m, and then put on the blindfold again. The *throwers* were told to walk to the target instead. Both groups walked to the target blindfolded, and the experimenter followed the participants to prevent them from walking into the walls.

Results and Discussion

We ran a 2 (intention) x 2 (sex) ANOVA with blindwalked distance as the dependent measure. The effect of intention on blindwalked distance was not significant ($F(1, 20) = 0.09$, $p > .7$). The *throwers* walked just as far as the *walkers* (see figure 4). Both groups walked short of the target. Previous research demonstrates that blindwalking tends to be accurate (e.g. Philbeck & Loomis, 1997), so it is unclear why these participants walked short of the target. There was no effect of sex on blindwalked distance ($F = 1.45$, $p > .20$), and the interaction between sex and intention was not significant ($F = 1.70$, $p > .20$). The design of this experiment was similar to experiment 1 except that neither group walked on the treadmill. The difference in walked distance in experiment 1 is therefore due to differences in perceived distance and not because one group was uncomfortable walking without prior knowledge of the task.

General Discussion

We investigated whether effort and intention influence perception directly, or whether they exert their effects during post-perceptual processes that are involved in generating a response. Two groups of participants walked on a treadmill, which increased their anticipated effort for walking because their perceptual/motor system learned that it took effort to go nowhere. Afterwards, one group looked at a target with the intention to blindwalk to it while another group looked at the target with the intention to blind throw to it. After donning a blindfold, we instructed both groups to walk to the target, so for both groups, our measure of perceived distance was a blindwalking estimate. We found that the *walkers* blindwalked farther than the *throwers*.

The only difference between the groups occurred when they were viewing the target (see figure 1). The *throwers* viewed the target with the intention to throw and the *walkers* viewed the target with the intention to walk. Once vision was occluded, we told both groups to walk to the target, thus both groups had the intention to walk at the time that the walking response was generated and executed. These results demonstrate that effort and intention affect perception directly. If effort and intention had exerted their effects during post-perceptual processes, both groups would have walked equally far because both groups experienced the same effort manipulation and both groups intended to walk at the time that their response was generated.

This pattern of results with blindwalking replicates our previous findings with verbal reports (Witt et al 2004; see figure 3). Targets looked farther away after walking on a treadmill when participants viewed the target with the intention to walk compared with participants who intended to throw. Since effort and intention influence perception, both indices of perceived distance – blindwalking and verbal reports – were affected. Thus, we have demonstrated an effect of effort and intention using converging measures of perceived distance.

Our account of perceptual recalibration compliments earlier studies by Rieser et al (1995) in their experiments, which also used a treadmill manipulation. Rieser et al used an ingenious method of dissociating forward walking speed and optic flow. They put a treadmill on a trailer being pulled by a tractor, so they could manipulate the speed of the treadmill independently of the speed of the tractor. Participants first walked on the treadmill while the tractor pulled it and then attempted to blindwalk to targets placed in a field. Rieser et al found that when the treadmill speed was set faster than the tractor speed, participants blindwalked past the target, and when the treadmill was set slower than the tractor, participants blindwalked short of the target. They interpreted these results as a visuomotor adaptation; however, their results are also consistent with our account of effort, intention, and perception. When the treadmill was faster than the tractor, participants may have recalibrated such that they anticipated having to expend more energy to walk a prescribed distance, and thus, perceived the targets to be farther away and blindwalked farther. When the treadmill was slower than the tractor, participants may have learned that it does not take as much energy to walk a prescribed distance, and thus, may have seen the targets closer and then walked short of the target.

However, if the effects of recalibrating on the treadmill are purely visuomotor, then participants in the present study should have all blindwalked past the target since they all underwent the treadmill adaptation. Instead, we found that participants who intended to throw to the target blindwalked shorter than participants who intended to walk to the target.

Our results are consistent with recent findings that demonstrate that other aspects of a person's ability to act in the environment influence perception. For example, the efficacy with which one can reach to targets influences perceived distance. Targets within reach looked closer than targets beyond reach even when distance was held constant (Witt et al 2005). Participants reached and estimated the distance to targets that were beyond reach without a tool but were within reach when wielding a tool. When they reached with the tool, they estimated the targets to be closer compared with when they reached without the tool. Thus, their ability to reach to the targets affected their perception of the distance to the targets. However, holding a tool only influenced perceived distance when the perceiver intended to reach with it. Perceived distance was not affected when the participants simply held the tool but never reached with it.

Additional studies have demonstrated effects of efficacy on other aspects of spatial perception as well. The ability to hit softballs affected the apparent size of the softball (Witt and Proffitt 2005). We found a positive correlation between batting average for a softball game and the judged size of the softball immediately after that game. Batters who were hitting better perceived the ball to be bigger than batters who were not hitting well. Also, participants who were better at throwing darts into a target perceived the target to be bigger than participants who had more difficulty hitting the target (Wesp et al 2004). In addition, the ability to ascend or descend a hill affects the perceived slant of the hill (Proffitt et al 1995). Slants are judged to be the same whether viewing the hill from the bottom or the top. However, at 25º, hills look steeper from the top than from the bottom. This is also the angle at which it is still possible to ascend the hill, but it becomes biomechanically difficult to descend it. This difference in the affordance for walking may account for the difference in perceived slant at this angle. Thus, there are several demonstrations that multiple aspects of the perceiver including intention, physiological potential, and behavioral abilities influence multiple aspects of the perceived environment.

When studying perception, researchers typically want to know if perception is veridical. Yet, to most researchers, veridical means accurate relative only to the physical world, and they seek to understand the relationship between the perceived world and physical world. In contrast, we believe that in order to be veridical, perception needs to relate the physical world to the perceiver. A sprinter sees the world as a sprinter. A child sees the world as a child. A person confined to a wheelchair sees the world as someone who is confined to a wheelchair. Why should all of their perceptions be the same? The world affords different things to each of them, and what they see depends on their individual abilities. What is the perceptual ‘truth’ to one need not be the same perceptual ‘truth’ to another.

Moreover, it may be advantageous to perceive the world in terms of its energetic costs (Proffitt 2006). In order to survive, more energy needs to be consumed than expended; therefore, it is necessary to regulate energy expenditure. Perception is useful for planning long-term actions in energy-efficient ways because the energetic costs associated with the intended action are inherent in perception. For example, by seeing a hill as being steeper when wearing a heavy backpack or after going for a long run, perceivers can plan to walk more slowly, and thereby, avoid exhaustion.

In summary, we have provided considerable support that effort conditioned by intention influences perceived distance as measured with explicit awareness measures and action measures. These effects occur during the time when the target is viewed, not during post-perceptual processes when a response is being generated. These findings have significant implications for understanding the nature of perception because we have demonstrated that accounts of perception that only include optical and ocular-motor factors are incomplete. Perceived distance is a function of the perceiver's intentions and abilities to act as well as optical and ocular-motor variables.

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Figure Captions

Figure 1. Overview of the procedure in experiment 1 and a depiction of the participants' intentions throughout the course of the experiment.

Figure 2. The effect of effort for walking on blindwalking as a measure of perceived distance when intending to walk compared with when intending to throw. The actual distance of the target was 8m.

Figure 3. The effect of effort for walking on verbal estimates when intending to walk versus when intending to throw (taken from Witt et al 2004).

Figure 4. Blindwalked distance without walking on the treadmill. The Intend to Walk group was told they would walk and did, but the Intend to Throw group was told they would throw and after they closed their eyes, they were told to walk instead. The actual distance of the target was 8m.

Figure 1.

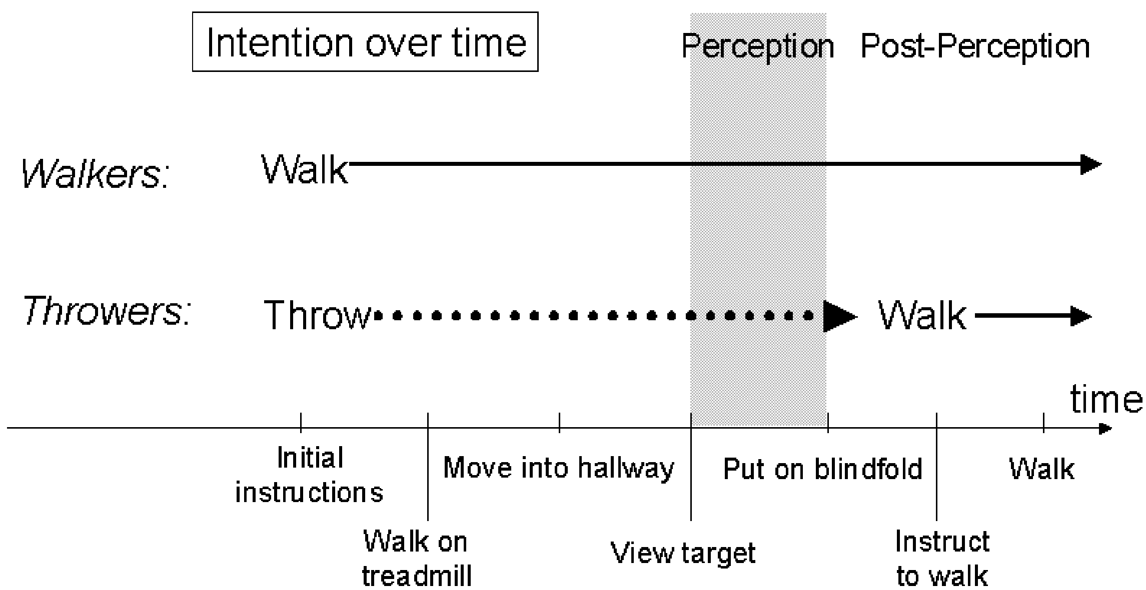

Intention over time
Perception
Post-Perception
Walkers:
Walk
Throwers:
Throw
Walk
time
Initial instructions
Walk on treadmill
Move into hallway
View target
Put on blindfold
Instruct to walk
Walk

Figure 2.

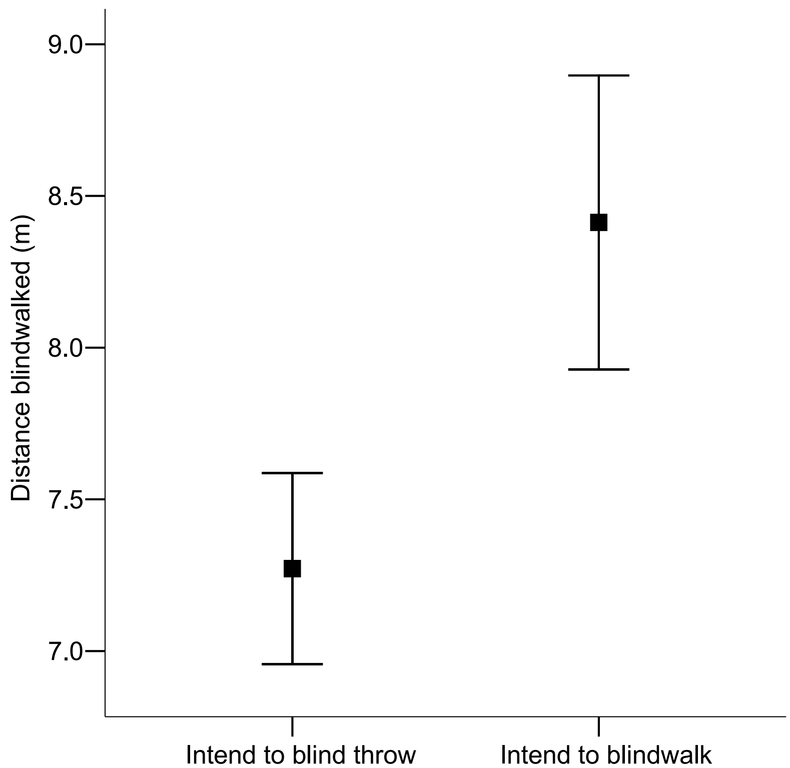

9.0
8.5
8.0
7.5
7.0
Distance blindwalked (m)
Intend to blind throw
Intend to blindwalk

Figure 3.

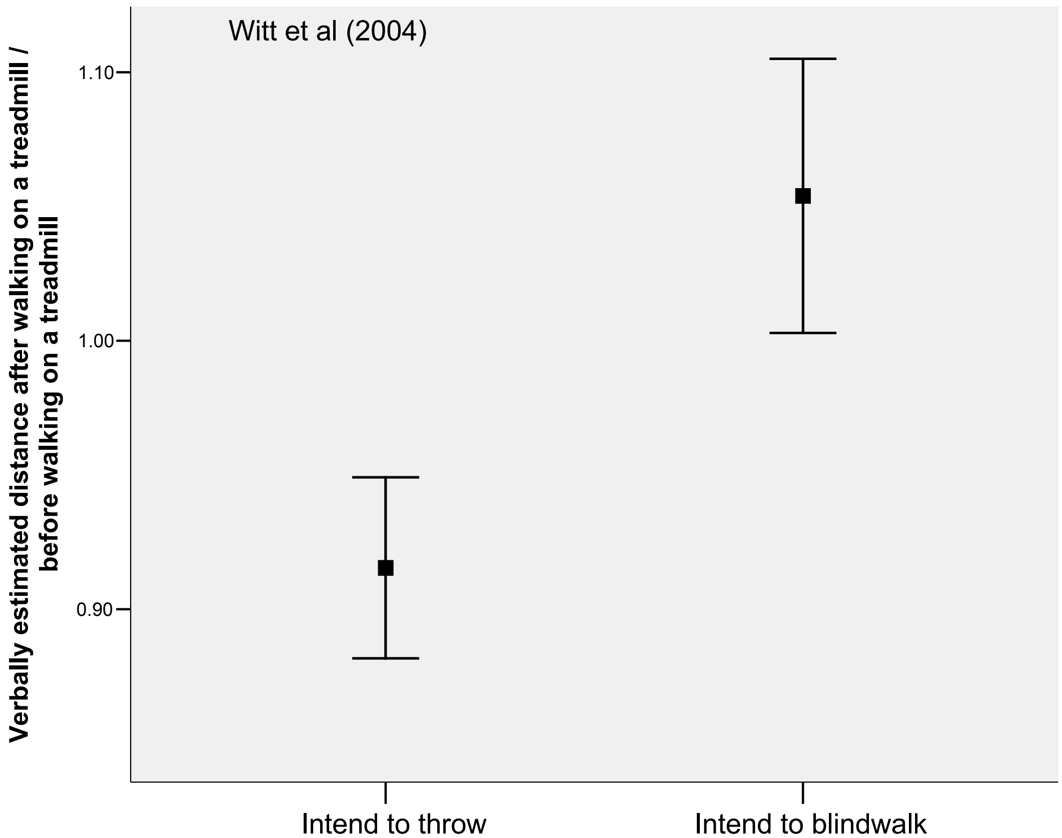
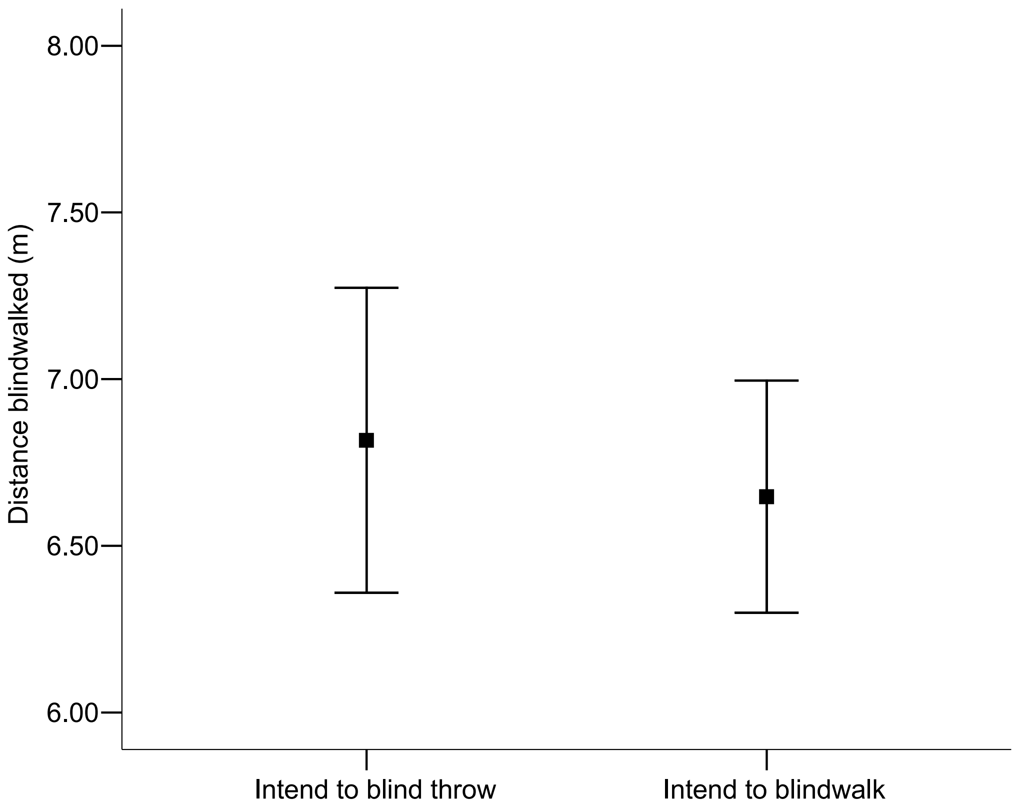

Witt et al (2004)
Verbally estimated distance after walking on a treadmill / before walking on a treadmill
1.10
1.00
0.90
Intend to throw
Intend to blindwalk

Figure 4.


8.00
7.50
7.00
6.50
6.00
Distance blindwalked (m)
Intend to blind throw
Intend to blindwalk