Throwing is affected by self-movement

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Abstract

This study aimed to investigate the influence of running on a treadmill on distance perception. Building upon previous research that demonstrates that, in an open field, targets are perceived further away when running on a treadmill compared to when standing, we sought to examine if this effect persisted within a shorter range of distances, suitable for a throwing task. Fourteen athletes (five women and nine men) with normal or corrected-to-normal vision and good physical condition participated in the study.

In Experiment 1, participants made distance estimates at 6 m, revealing a consistent compression effect and larger distance estimates during running. Experiment 2 utilized a throwing task to assess the accuracy of distance perception while running or standing static on a treadmill. Participants were required to throw balls into a hoop, aiming to put the ball through the hoop without visual feedback.

The results showed that running on a treadmill influenced distance perception, leading to larger estimates (DOR effect). However, participants exhibited accurate throwing performance regardless of running or static conditions, indicating that the altered distance perception did not affect their ability to accurately throw objects.

These findings suggest that the perception of distance is a process that relies on perceptual cues and sensorimotor feedback in a manner that resembles mutually inhibitory interactions between visual and proprioceptive motor information.

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Introduction

One of the most significant challenges for the brain is to perceive the space around us accurately, which is crucial for our interactions with the environment. This space perception may be shaped by the interaction of multiple sensory modalities. However, vision tends to dominate spatial judgments because it provides highly detailed spatial information that affects our perception of space and distance estimation (Eimer, 2004). Research has focused on distance perception in open fields by stationary observers (e.g., Norman et al., 2005; Silva, 1985). However, we and the world around us are in continuous relative movement, which suggests that our perceptual experience and motor actions must be shaped by interactions between our senses and the perception of our self-movement. Consequently, all the sources of information must be integrated into an internal model of whole-body motion with respect to the physical environment (Land, 2012), which must be learned and updated through experience (Wolpert & Flanagan, 2001).

Recently, Santillán and Barraza (2019) explored the effect of self-movement on the perception of egocentric distance. The authors used an indirect method to compare the perceived distance while running on a treadmill to the perceived distance while standing on the same treadmill. They found that when running, observers perceive objects as farther away compared to when standing. The authors hypothesized that proprioceptive motor input in the absence of visual motion produces a misperception of self-movement speed, similar to that observed after running on a treadmill (Anstis, 1995), which in turn produces a misperception of egocentric distance.

Some activities such as sports require fine coordination of movements (running, jumping, catching, etc.) and accurate distance estimations to place objects in specific locations (a goal, a basket, a target, etc.). An interesting case is that of basketball players when they have to pass the ball to the goal while moving forward, because the distance to the goal at the time of execution may differ from the distance estimated from the image acquired earlier, requiring the player to adjust their estimate. This recalibration is necessary for humans to successfully perform such skilled actions. The challenge arises because the distance estimate may be based on a snapshot of the scene, which becomes outdated if the player is moving at the time of execution. This situation is illustrated by Eq. (1).

$$D_f = D_i - v \cdot \Delta t$$

where D_i y D_f are the distances at the moments of the visual scene acquisition and at the action execution, respectively. They are obviously distinct if $v.\Delta t$ is different from zero. Therefore, in order to execute the action successfully, this distance difference has to be compensated. Indeed, practice shows that such compensation works as skilled athletes successfully achieve these actions. Δt is the time elapsed between the times i and f, and v is the speed of self-movement. An interesting question arises regarding the speed of self-movement (v). It is known that interoceptive and exteroceptive information are combined in the representation of self-motion (Durgin, 2009; Durgin et al., 2005; Durgin & Gigone, 2007) The authors showed that the perceived speed of motion-in-depth induced by a simulated flow field decreases when an observer walks on a treadmill. They proposed that the perceived speed of locomotion would be determined by a visual component, i.e., the visual speed contained in the optic flow, minus some proportion of the non-visually perceived speed of self-motion, as shown in Eq. (2).

$$v_p = v_{visual} - k \cdot v_{nonvisual}$$

This model derives from the idea that mutually inhibitory interactions between simultaneously activated units may promote more efficient coding (Barlow & Földiák, 1989). This could explain the improvements in perceptual discrimination observed when two different sources of visual information are correlated. Furthermore, as was suggested by Santillán and Barraza (2019), this model accounts for the overestimation of egocentric distance obtained while running on a treadmill. The authors proposed that the speed of self-movement (v) in Eq. 1 is the perceived speed of locomotion. Therefore, if we replace v_p of Eq. 2 in Eq.1 and consider the visual component of speed (v_{visual}) as zero, obtain

$$D_f = D_i + k \cdot v_{nonvisual} \cdot \Delta t$$

where $v_{nonvisual}$ is the proprioceptive motor input. Consistently with Santillán and Barraza's results, Eq. 3 suggests that perceived distance while running on the treadmill will be larger than that obtained standing on the same treadmill.

In this study, we propose to test whether this perceptual overestimation has a correlation with the action of throwing a ball to a basket. To do this we performed an experiment in which we compared the throwing distance obtained in two conditions namely, running and standing on a treadmill.

General Methods

In this study, we employed the paradigm of indirect distance indication, utilizing judgments of perceived exocentric extent in the fronto-parallel plane, as well as employing throwing as a means to gauge the participants' perceived distance. These methods were chosen to minimize the influence of prior knowledge or beliefs on distance judgments, as often encountered in verbal estimation tasks (Loomis & Philbeck, 2008; Pan et al., 2014). Building upon the findings of Santillán and Barraza (2019), who demonstrated that human observers perceive objects as farther away while running on a treadmill compared to standing on the same treadmill for distances ranging from 12 m to 32 m, we sought to investigate if this effect persisted within a shorter range, more suitable for a throwing task. For clarity, we will name this effect as Distance Overestimation while Running (DOR).

Ethical approval for the study protocol was obtained from the Committee for Ethical Research of the National University of Tucumán, Argentina, and all procedures adhered to the principles outlined in the Declaration of Helsinki and the ethical guidelines set forth by the American Psychological Association regarding research involving human subjects. The participants included in the study were athletes in optimal physical condition, capable of performing the required tasks, which involved periods of running on the treadmill. Prior to their involvement, participants provided informed consent and any queries they had were addressed.

Location and apparatus

The experiments were conducted in an indoor setting, specifically a 10x10 m room within the Faculty of Physical Education at the National University of Tucumán. This room was specifically designed for research purposes, with white walls, a white floor, thermal control, and artificial lighting. It provided a controlled environment free from obstacles or unnecessary objects. To manipulate the perceived distance, we utilized a treadmill (PROTEUS MTM-5600 with digital speed selector) placed on a platform with steel wheels mounted on rails. This setup allowed us to move the participants, along with all immediate treadmill-related references (e.g., control panel), while maintaining the target at a fixed position.

Experiment 1

The objective of this experiment was to examine whether the DOR effect previously observed in the open field also applies to distances suitable for shooting a ball into a hoop. To achieve this, we employed a modified version of the indirect distance estimation method previously utilized (Santillán & Barraza, 2019). This method involved establishing a correspondence between the distance to be estimated in the sagittal plane (target) and another distance in the frontal plane (indicator). An assistant would manipulate the indicator distance until the participant perceived both distances as similar.

Methods

The test conditions were 1) Standing (on the treadmill), and 2) Running (at a speed of 6 km/h on the treadmill). Based on our previous experiments, we expected, in both cases, an underestimation of the target distance consistent with the compressive effect shown by Wagner (1985).

Participants

We recruited a total of 14 students from the Physical Education School (nine men and five women) who voluntarily participated in this study. The sample size exceeded the minimum requirement determined by the G-Power analysis. None of the participants were aware of the specific objectives of the experiment prior to their involvement. The age range of the participants was between 18 and 30 years, with a mean age of 23 years. All participants had a normal or corrected-to-normal vision and were in good physical condition.

Procedure

Participants were led to the treadmill and then explained what they should do. The order in which participant performed conditions were balanced and determined randomly. In the case of motor stimulation, he was adapted to a running pace of 6 km/h for one minute, and then he had to perform the task while running at that speed. Otherwise, he just stood still. As it is known from previous studies, running for one minute is enough to produce adaptation (Durgin et al., 2005), which we could verify in the pilot experiments. The target was a hoop 165 cm tall, and the indicator was a white stake of the same height with a tripod that allowed it to remain vertical at the point determined by the observer. It had a high-visibility orange fluorescent mark (20 cm) located on the top. Although the egocentric distance between the participant and the target was always 600 cm, we varied the position of the treadmill and the target between measurements to prevent them from using background or ground details as references when estimating the distance in the frontal plane. They were strongly asked to ignore external references (e.g., the assistant's height) when comparing distances and to focus specifically on their distance to the target and between the target and the indicator. The procedure consisted of moving the indicator linearly, from a position close to the target, until the participant considered that his egocentric distance from the target was similar to the exocentric distance target-indicator, at which point he had to say "stop". They were asked to close their eyes, we proceeded to mark the position and then the process was restarted and performed 5 times for each condition.

Results

The boxplot of Figure 2 shows the matching distance for both conditions. As can be observed, matching distances are much shorter than 600 cm, which was the reference distance. This is an expected result, consistent with previous studies (Loomis et al., 1992; Norman et al., 2005; Santillán & Barraza, 2019), and shows the well-known compressive effect of distance perception of the in-depth dimension (Wagner, 1985).

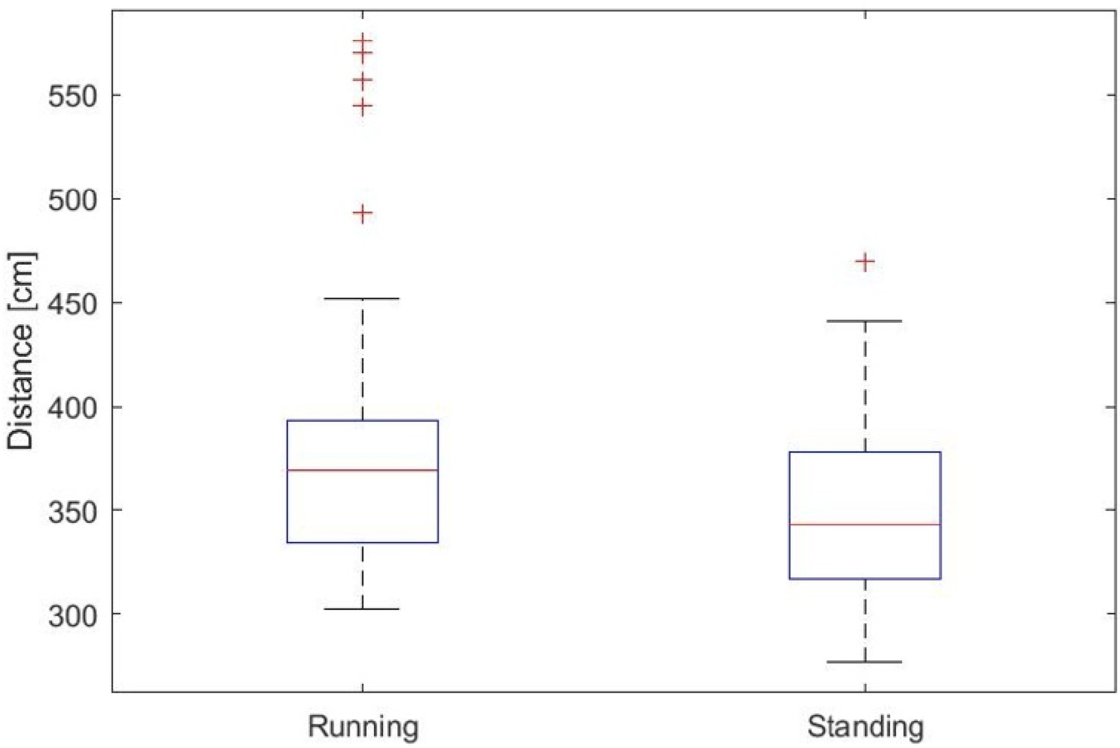

Figure 2. Matching distance for both conditions: Running and Standing. The reference distance was 6 m.

Importantly, the plot shows that the matching distance for the running condition is larger than that obtained for the standing condition, which indicates that the effect of self-movement on the egocentric distance perception holds for this range of distances. A paired-sample t-test indicates that matching distances obtained in both conditions are statistically different ($p<0.001$).

Experiment 2

The results of Experiment 1 demonstrated the presence of perceived distance compression at a distance of 6 m, indicating that running on a treadmill influences distance perception and leads to larger distance estimates (known as the DOR effect). In this experiment, we aim to further investigate this effect by utilizing an action-based approach to assess perception, as suggested by previous studies (Loomis & Philbeck, 2008; Philbeck & Witt, 2015). These studies propose that action can serve as a reliable measure of space perception, provided that postperceptual processes do not introduce systematic biases or that they can be corrected through calibration (while acknowledging that the precision of measurement may be limited by random noise associated with subsequent processes).

To examine this, we employed a model of perceptually directed action based on a representation of space in memory. Initially, various stimuli (visual, haptic, auditory) contribute to the percept, which includes the location of the target. The relationships between perceived objects are represented in memory and persist even after the perceptual experience ends. It is assumed that the mental image in memory aligns with the percept, and any errors or biases in the memory image are transferred to the mental spatial image. Although changes in the subject's position information are updated, the mental image remains fixed in relation to the physical environment (Loomis et al., 1992).

Previous studies have observed altered relationships between vision and proprioceptive cues during treadmill walking while being pulled by a tractor (Rieser et al., 1995). Similarly, we observed a similar influence on distance estimation when subjects ran on a treadmill with and without altered frontal optic flow velocity (Santillán & Barraza, 2019). Notably, as highlighted by Loomis and Philbeck (2008), adaptation to these altered relationships produces systematic changes in blindfolded walking distances to previously observed targets but does not affect throwing an object to the position of those targets. To examine this further, we designed an experiment based on the concept of shooting a ball through a hoop, similar to certain ball sports.

Methods

The task consisted of throwing a ball into a hoop without the aid of vision under the two conditions used in Experiment 1, that is, standing static on top of the treadmill or running at a velocity of 6 km/h. The targets used were hoops with heights of 160 cm and 40 cm.

Participants

The same 14 subjects from Experiment 1 participated here as well. All were unaware of the purpose of the experiment and had never participated in such an experiment. This avoided any influence of previous learning, and allowed everyone to have the same amount of practice time with the equipment used.

Procedure

Participants who were already familiar with the layout were briefed on the new task upon assuming their positions. Similar to the previous experiment, the order of conditions was randomized and balanced across participants. Hence, half of the participants began with the running condition, while the other half started with the standing condition. Additionally, half of the participants started with the low hoop, and the remaining half with the tall hoop. As in Experiment 1, participants who underwent motor stimulation were adjusted to a running pace of 6 km/h before executing the task.

Each participant had a brief practice session to familiarize themselves with the task, during which they alternated between throwing from distances of 650 cm and 550 cm. The test distance remained consistent at 600 cm. It is worth noting that while all participants had some experience with sports, including basketball, they were not familiar with the specific parameters of the task, such as hoop height (160 cm and 40 cm), hoop diameter (36 cm), and ball size and weight (13 cm and 100 g).

Once participants felt ready, the trials commenced. They were instructed to carefully observe and memorize the distance and position of the hoop. Subsequently, their vision was obstructed by a panel, preventing them from seeing the actual location of the hoop or the marks indicating the ball's impact. In each of the eight blocks of trials (2 conditions x 2 heights x 2 repetitions), participants were required to throw 9 balls over the panel, aiming to accurately place the ball into the hoop. Their objective was to successfully score by putting the ball through the hoop. While one assistant handed over the balls, another assistant marked the point of impact on the floor. Participants were informed that the hoop would be removed to eliminate any feedback from the sound produced when the balls hit the hoop. This arrangement also ensured that neither the hoop nor the support structure obstructed the parabolic trajectory of the ball or impeded the determination of the point of impact on the floor. Following each series of shots, participants were given a rest period while the assistants retrieved the balls for the next measurement. Adjacent to the panel, there was a ruler extending 2 m from its edge. Each shot was recorded on video to capture the height at which the ball passed the ruler, enabling the reproduction of the ball's parabolic trajectory (refer to Figure 1).

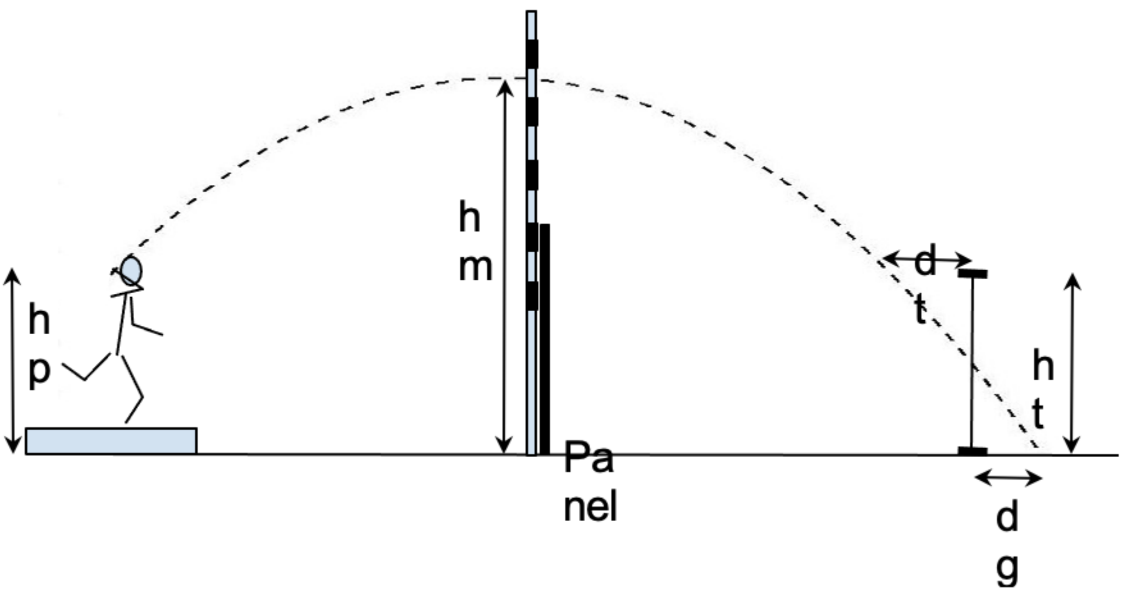

Figure 1. Side view of the observer throwing the ball. The figure includes a dotted line of its trajectory making the parabola,

the loop, the panel to obstruct the vision, the ruler with which the height of the shot was measured, and the horizontal ruler on the ground where the point of impact was recorded.

Results

In this experiment, we investigated the effect of self-movement on the throwing distance for two different target heights. Fourteen participants performed eighteen throws for each condition and target height, which led to a total of n=1008 throws to be included in the Two-Way ANOVA. The analysis revealed significant effects for the Condition factor ($F(1, N) = 36.42$, $p < 0.001$) and the Height factor ($F(1, N) = 69.32.2$, $p < 0.001$). Furthermore, there was a significant interaction between Condition and Height ($F = 9.87$, $p < 0.001$).

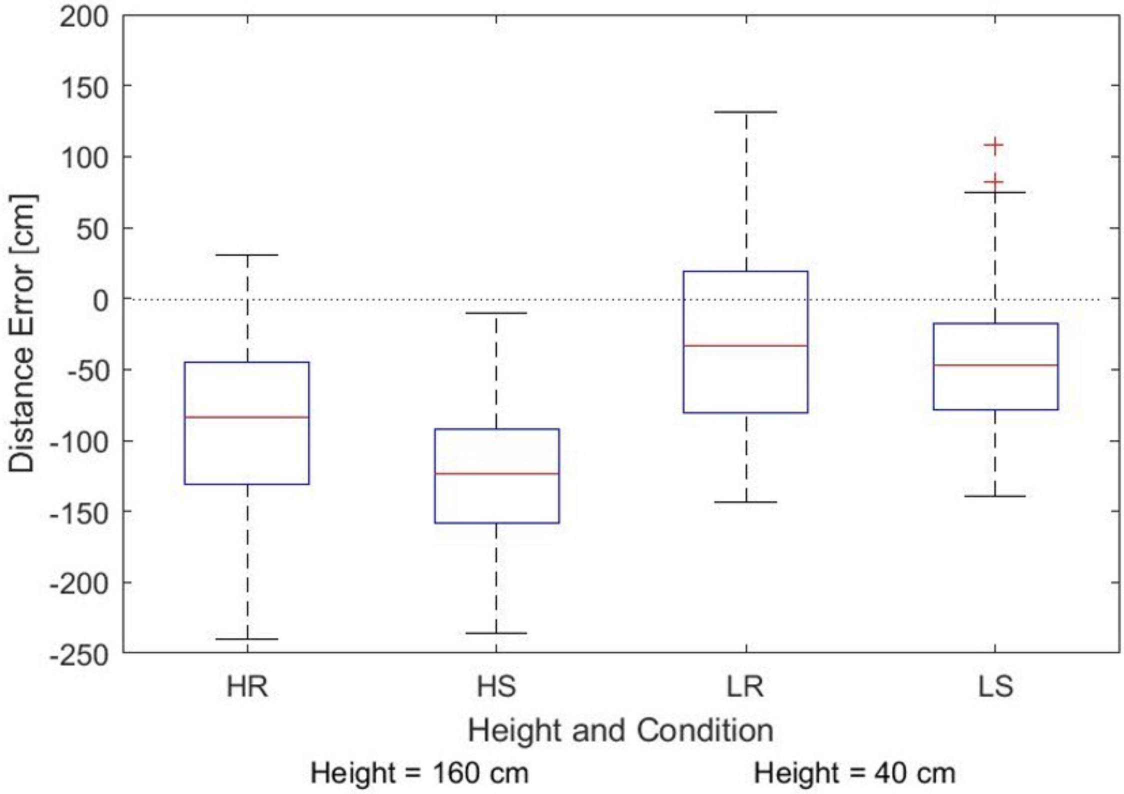

Figure 3. Throwing distance to the target at the target's height for both conditions: Running and Standing. HR, HS, LR, and LS mean High-Running, High-Standing, Low-Running, and Low-Standing, respectively.

Figure 3 shows the error (dt in Figure 1), defined as the difference between the throw distance at the target's height and the target's distance, for both conditions and heights. Negative values indicate that the throw fell short. Importantly, participants consistently threw the ball further when running on the treadmill compared to when standing, regardless of the target height (HR vs HS and LR vs LS). Paired-sample t-tests revealed significant differences in both cases ($p<0.001$). These findings align with the predictions of our model and the results of the first experiment, suggesting that participants throw the ball farther in the running condition due to a perceived increase in target distance.

Discussion

In daily life situations, where motor actions such as movements and throws are performed naturally to reach a goal, the brain faces a significant challenge: analyzing and integrating information from multiple senses to form an accurate representation of the environment and one's own movement within it. The problem begins with detecting signals from the environment, which are often noisy and ambiguous. In addition to various strategies employed by the visual system to reduce uncertainty, the combination of visual and motor information can lead to improved visual perception. While vision has traditionally been considered dominant in these kinds of multisensory processes (Welch & Warren, 1986), models of intersensory integration (Van Beers et al., 1996, 1999) propose that information from both senses is optimally weighted to generate perception. Consequently, the accuracy of actions can be significantly influenced by conflicting visual information (Guerraz et al., 2012; Van Beers et al., 1999)

According to our rationale, as formalized in Eq. 3, the overestimation observed in the Running condition can be attributed to the presence of locomotive proprioceptive information without corresponding visual information. This discrepancy in sensory inputs would distort the computation of the distance used for the throwing action (Santillán & Barraza, 2019). It is worth noting that this effect was artificially induced in the laboratory to test our hypothesis and may not commonly occur in real-life situations. Nevertheless, the findings of this study are crucial as they contribute to our understanding of how the brain integrates visual and proprioceptive motor information.

One complication in the interpretation of these results is the possibility that the longer throws observed while running on the treadmill may be attributed to an effect exerted by the running condition on the throwing technique, leading participants to naturally throw with greater force, resulting in longer distances. However, due to the nature of our experimental design, we were unable to directly test this alternative explanation.

Secondly, examining the results in the standing condition, it can be observed that the errors are negative in both cases, which indicates that participants always shoot short. This is more noticeable for the higher target, around -124 cm, against -46.5 cm in the case of the low target. Why do participants throw systematically short? Is it just a problem of accuracy due to a lack of expertise?

Several studies (for example, Eby & Loomis, 1987; Elliott, 1986; Foley, 2021; Loomis et al., 1992; Philbeck et al., 1997; Sahm et al., 2005; Thomson, 1983) have previously approached the problem of egocentric distance perception through the execution of visually directed actions since it was hypothesized that they provide a relatively pure measure of perceived distance (Loomis & Philbeck, 2008). Although there are divergences in some results (Corlett et al., 1985; Elliott, 1986; Loomis et al., 1992; Thomson, 1983) all agree that the participants are quite accurate when walking and throwing without the aid of vision, particularly up to 10 meters away. However, Foley (2021) notes that "when people throw an object at a nearby target in a novel situation, they often throw it short." He suggests that other investigators found more accurate results due to participants having performed some kind of training. What is striking about our results in Figure 3 is that the Distance Error is dependent on the height. This dependence could not be explained, in principle, in the context of the cited literature since both targets were at the same physical distance from the observer. The explanation, according to us, lies in what feature or data of the scene the participants are taking as a reference to estimate the distance.

Figure 4 shows the error (dg in Figure 1), defined as the difference between the throw distance at ground height and the target's distance. It is noteworthy that the error is minimal in both Standing Conditions, measuring 4.5 cm for HS and 14.5 cm for LS. This suggests that participants are actually aiming at the base of the target rather than the actual target (hoop). It is worth mentioning that many experiments involving visually guided actions have utilized targets positioned on the ground. For instance, Philbeck et al. (Philbeck et al., 1997) conducted an experiment with targets at eye level, and when the lights were turned off, participants could not perceive the target support on the ground (relying solely on the self-illuminated target), resulting in significantly larger errors compared to when the lights were on. Although not originally part of the study's objectives, this result is intriguing and deserves further investigation in future research as it has the potential to contribute significantly to the space perception models.

Finally, as depicted in Figure 4, it is evident that the effect of running on the treadmill persists in the throwing distance at the ground height, exhibiting even more substantial differences compared to those obtained at the target height.

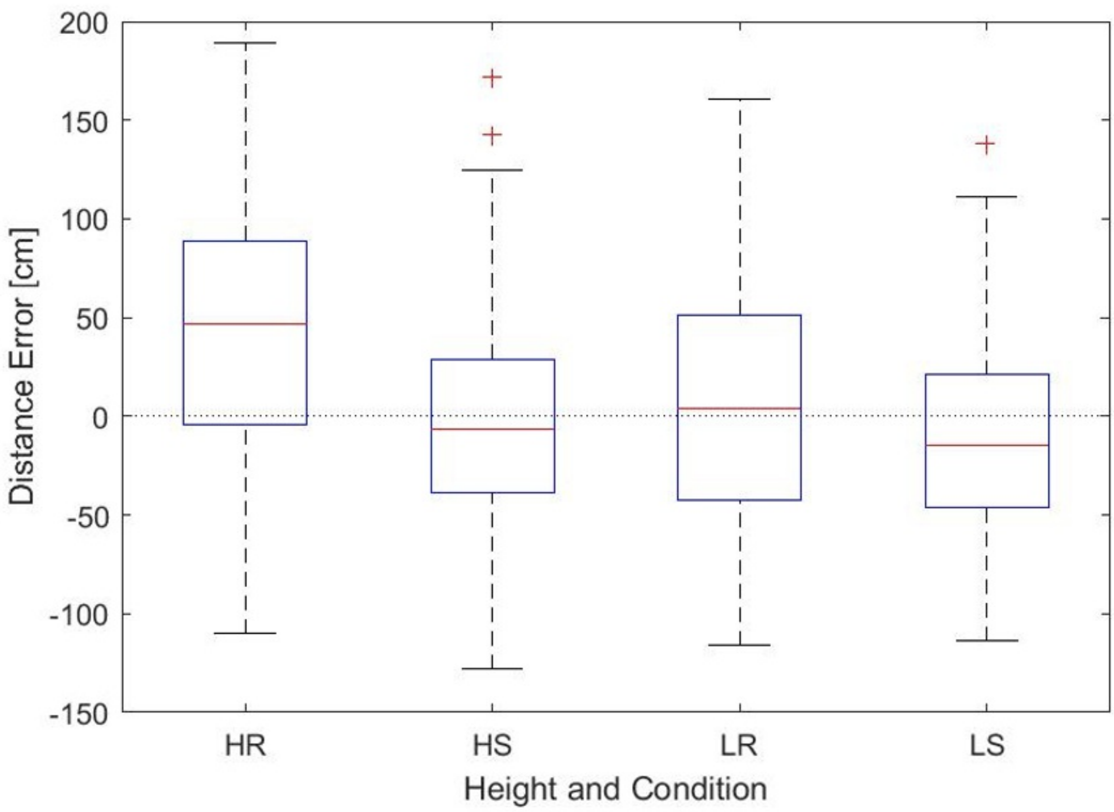

Figure 4. Throwing distance to the target at the ground's height for both conditions: Running and Standing. HR, HS, LR, and LS mean High-Running, High-Standing, Low-Running, and Low-Standing, respectively.

References

- Anstis, S. (1995). Aftereffects from jogging. Experimental Brain Research, 103(3).https://doi.org/10.1007/BF00241507

- Barlow, H. B., & Földiák, P. (1989). Adaptation and decorrelation in the cortex. In R. Durbin, C. Miall, & G. Mitchison (Eds.). In The computing neuron (pp. 54-72). Addison-Wesley.
- Corlett, J. T., Patla, A. E., & Williams, J. G. (1985). Locomotor Estimation of Distance after Visual Scanning by Children and Adults. Perception, 14(3), 257-263. https://doi.org/10.1068/p140257
- Durgin, F. H. (2009). When Walking Makes Perception Better. Current Directions in Psychological Science, 18(1), 43-47. https://doi.org/10.1111/j.1467-8721.2009.01603.x
- Durgin, F. H., & Gigone, K. (2007). Enhanced Optic Flow Speed Discrimination While Walking: Contextual Tuning of Visual Coding. Perception, 36(10), 1465-1475. https://doi.org/10.1068/p5845
- Durgin, F. H., Pelah, A., Fox, L. F., Lewis, J., Kane, R., & Walley, K. A. (2005). Self-Motion Perception During Locomotor Recalibration: More Than Meets the Eye. Journal of Experimental Psychology: Human Perception and Performance, 31(3), 398-419. https://doi.org/10.1037/0096-1523.31.3.398
- Eby, D. W., & Loomis, J. M. (1987). A study of visually directed throwing in the presence of multiple distance cues. Perception & Psychophysics, 41(4), 308-312. https://doi.org/10.3758/BF03208231
- Eimer, M. (2004). Multisensory Integration: How Visual Experience Shapes Spatial Perception. Current Biology, 14(3), R115-R117. https://doi.org/10.1016/j.cub.2004.01.018
- Elliott, D. (1986). Continuous visual information may be important after all: A failure to replicate Thomson (1983). Journal of Experimental Psychology: Human Perception and Performance, 12(3), 388-391. https://doi.org/10.1037/0096-1523.12.3.388
- Foley, J. M. (2021). Visually directed action. Journal of Vision, 21(5), 25.https://doi.org/10.1167/jov.21.5.25
- Guerraz, M., Provost, S., Narison, R., Brugnon, A., Virolle, S., & Bresciani, J.-P. (2012). Integration of visual and proprioceptive afferents in kinesthesia. Neuroscience, 223, 258-268. https://doi.org/10.1016/j.neuroscience.2012.07.059
- Land, M. F. (2012). The Operation of the Visual System in Relation to Action. Current Biology, 22(18), R811-R817. https://doi.org/10.1016/j.cub.2012.06.049
- Loomis, J. M., da Silva, J. A., Fujita, N., & Fukusima, S. S. (1992). Visual space perception and visually directed action. Journal of Experimental Psychology: Human Perception and Performance, 18(4), 906-921. https://doi.org/10.1037/0096-1523.18.4.906
- Loomis, J. M., & Philbeck, J. W. (2008). Measuring spatial perception with spatial updating and action. In R. L. Klatzky, B. MacWhinney, & M. Behrman (Eds.), Embodiment, ego-space, and action (pp. 1-43). Psychology Press.
- Norman, J. F., Crabtree, C. E., Clayton, A. M., & Norman, H. F. (2005). The Perception of Distances and Spatial Relationships in Natural Outdoor Environments. Perception, 34(11), 1315-1324. https://doi.org/10.1068/p5304
- Pan, J. S., Coats, R. O., & Bingham, G. P. (2014). Calibration is action specific but perturbation of perceptual units is not. Journal of Experimental Psychology: Human Perception and Performance, 40(1), 404-415. https://doi.org/10.1037/a0033795
- Philbeck, J. W., Loomis, J. M., & Beall, A. C. (1997). Visually perceived location is an invariant in the control of action. Perception & Psychophysics, 59(4), 601-612. https://doi.org/10.3758/BF03211868
- Philbeck, J. W., & Witt, J. K. (2015). Action-specific influences on perception and postperceptual processes: Present

controversies and future directions. Psychological Bulletin, 141(6), 1120-1144. https://doi.org/10.1037/a0039738

- Rieser, J. J., Pick, H. L., Ashmead, D. H., & Garing, A. E. (1995). Calibration of human locomotion and models of perceptual-motor organization. Journal of Experimental Psychology: Human Perception and Performance, 21(3), 480-497. https://doi.org/10.1037/0096-1523.21.3.480
- Sahm, C. S., Creem-Regehr, S. H., Thompson, W. B., & Willemsen, P. (2005). Throwing versus walking as indicators of distance perception in similar real and virtual environments. ACM Transactions on Applied Perception, 2(1), 35-45. https://doi.org/10.1145/1048687.1048690
- Santillán, J. E., & Barraza, J. F. (2019). Distance perception during self-movement. Human Movement Science, 67, 102496. https://doi.org/10.1016/j.humov.2019.102496
- Silva, J. A. D. (1985). Scales for Perceived Egocentric Distance in a Large Open Field: Comparison of Three Psychophysical Methods. The American Journal of Psychology, 98(1), 119. https://doi.org/10.2307/1422771
- Thomson, J. A. (1983). Is continuous visual monitoring necessary in visually guided locomotion? Journal of Experimental Psychology: Human Perception and Performance, 9(3), 427-443. https://doi.org/10.1037/0096-1523.9.3.427
- Van Beers, R. J., Sittig, A. C., & Gon, J. J. D. V. D. (1999). Integration of Proprioceptive and Visual Position-Information: An Experimentally Supported Model. Journal of Neurophysiology, 81(3), 1355-1364. https://doi.org/10.1152/jn.1999.81.3.1355
- Van Beers, R. J., Sittig, A. C., & Van Der Gon Denier, J. J. (1996). How humans combine simultaneous proprioceptive and visual position information. Experimental Brain Research, 111(2), 253-261. https://doi.org/10.1007/BF00227302
- Wagner, M. (1985). The metric of visual space. Perception & Psychophysics, 38(6), 483-495. https://doi.org/10.3758/BF03207058
- Welch, R. B., & Warren, D. H. (1986). Interasensory Interactions. In K. R. Boff (Ed.). In Handbook of perception and human performance (p. 25.1-25.36). Wiley.
- Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. Current Biology, 11(18), R729-R732. https://doi.org/10.1016/S0960-9822(01)00432-8