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Honors Thesis

ANGULAR SCALE EXPANSION OF ADULTS AND CHILDREN

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ANGULAR SCALE EXPANSION OF ADULTS AND CHILDREN

How do people perceive and judge distances? What makes some people more accurate than others in their estimation of egocentric distances? There is some controversy over the existence and cause of systematic error that people make in judging distances. Different sets of perceptual information can be effective in judging distances, depending on viewing conditions (Li & Durgin, 2012). For the purpose of my thesis, I wish to limit the discussion to the perception and estimation of egocentric distance in depth under full cue conditions in an outdoor environment. In other words, I am particularly interested in examining people's perception and judgments of ground distances between target objects and themselves on an open, grassy field. Before describing the current study in more detail, I wish to review previous studies that have found systematic perceptual biases in spatial perception and the theories that have been posited by various researchers to explain these biases.

Geometric Accounts of Space Perception

One framework proposed to explain distance judgments is that there exist systematic biases in perceived egocentric distance. Specifically, previous studies have found that, based on explicit verbal measures, egocentric distances are normally underestimated (e.g., Da Silva, 1985). Drawing from these findings of underestimation, researchers have claimed that the perception of egocentric distance is far from accurate.

However, there is some disagreement among these researchers regarding the exact nature of error in egocentric distance judgments. Some researchers have claimed that perceived egocentric distance is increasingly compressed at farther distances (e.g., Gilinsky, 1951), whereas others have claimed that it is approximately constantly compressed at all distances (e.g., Li, Phillips, & Durgin, 2011). For example, Gilinsky (1951) claimed that egocentric distances are compressed in a non-linear fashion. According to this so-called "hyperbolic" model, perceived ground distance in visual space is increasingly compressed at greater distances (Li, Phillips, & Durgin, 2011). Notably, Gilinsky's conclusion was based on the comparison of exocentric distances, rather than egocentric ones.

There is a reason to believe that different models are required to explain exocentric versus egocentric distance judgments. For instance, in a study that examined perception of both egocentric and exocentric distances, Li, Phillips, and Durgin (2011) found that the compression of egocentric distances could be explained by a *constant* factor of about 0.7 (also see Loomis & Philbeck, 2008). Notably, Li, Phillips, and Durgin (2011) used a nonverbal method in which participants were asked to match vertical and frontal extents with distances. This means that, unlike in studies based on verbal estimations of distance, results of Li, Phillips, and Durgin (2011) are unlikely to an artifact of scaling error. The fact that perception underestimates egocentric distances by a constant ratio implies that perceived egocentric distance is compressed, but not compressive as predicted by the hyperbolic model. Indeed, Li, Phillips, and Durgin (2011) claimed that egocentric distance estimates are approximately linear with increasing distances. Even though there is slightly more perceptual compression for farther egocentric distances, the data do not fit to the hyperbolic model; unlike the compression of perceived exocentric distances, the compression of egocentric distances has an exponent of only slightly lower than 1.0.

It is important to consider the reason why there is such a difference between the perception of exocentric distances and that of egocentric distances. One source of perceptual information that is of particular interest in examining egocentric distance perception is information regarding direction of gaze (Li, Phillips, & Durgin, 2011). Indeed, several theorists have suggested for some time that people use gaze direction toward a point on ground as a cue for judging egocentric distance to that point (Wallach & O'Leary, 1982). For example, Li and Durgin (2010) claimed that people mainly rely on *gaze declination* from the horizontal when judging egocentric ground distance, whereas people rely on *optical slant* (the orientation of the surface to be judged relative to the gaze direction) when judging exocentric ground distance. The question then is how gaze declination toward targets on the ground leads to the documented underestimation bias in perceived egocentric distance. In order to answer this question, it is important to examine people's perception of their own gaze declination and see if there is a systematic bias in this perception.

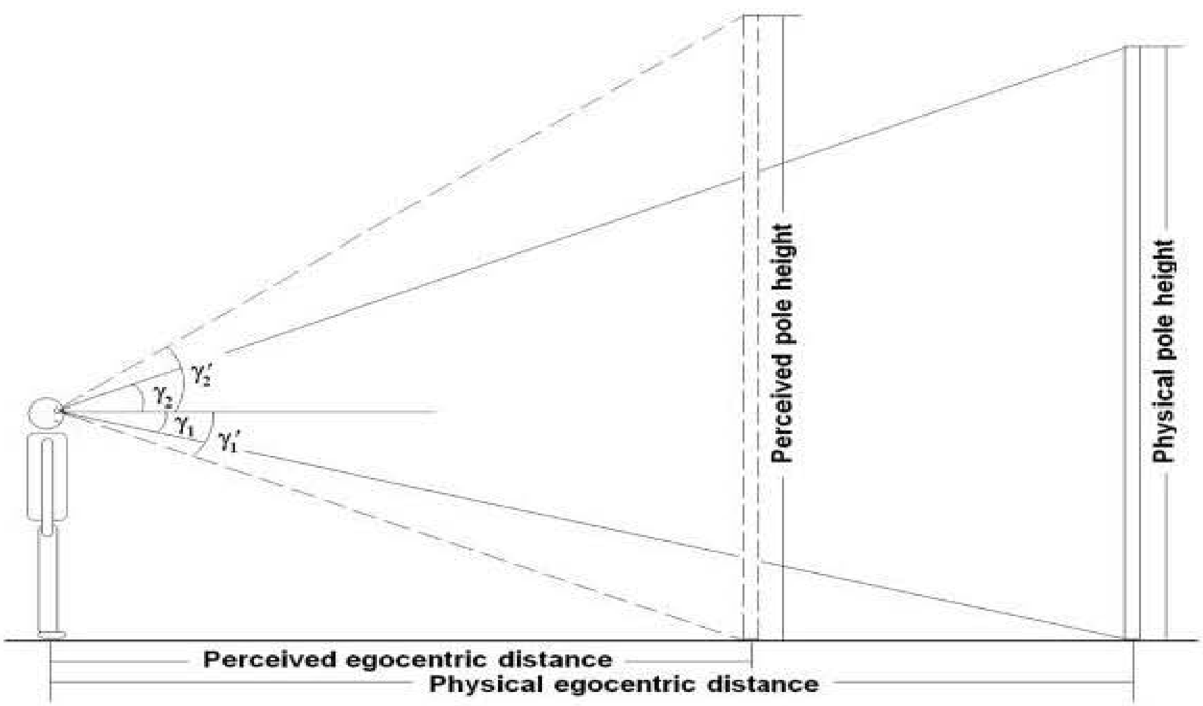

Figure 1. An illustration from Li et al. (2013) that demonstrates how a misperception in angular declination of gaze can account for the empirical findings on systematic underestimation of egocentric distance. Angular gaze declination is exaggerated by a factor of 1.5, and egocentric matches to vertical extents are biased in a way that is consistent with this 1.5 gain in angular declination.

Durgin and Li (2011) is an example of a study in which participants estimated their gaze declination toward targets on the ground. Interestingly, Durgin and Li (2011) found that people overestimated their gaze declination by a factor of 1.5 when they were asked to provide explicit perceptual estimates of the declination angle. This angular expansion was replicated in another study reported in the same article, in which participants were asked to view a suspended ball from above and to place it at a visual direction that bisected the horizontal and the vertical. Participants again overestimated their gaze declination, as evidenced by the fact that the mean perceived bisection angle was 31° below the horizontal axis. As Durgin and Li (2011) pointed out, the underestimation of egocentric distance may be a result of this overestimation of angular declination. Using the term used by the authors themselves, I will refer to the proposal of Durgin and Li (2011) as the angular expansion hypothesis (Figure 1).

What is interesting about the angular expansion hypothesis is that it points to misperception of a particular angular variable as a source of the underestimation bias in judging egocentric distance. Based on this hypothesis, a local misperception of angular declination results in systematic distortions of visual space that are nevertheless consistent with Euclidean anaylses, at least on a local level (Li & Durgin, 2012). This conclusion stands in sharp contrast to past studies that argued for non-Euclidean properties of visual space (e.g., Koenderink et al., 2000). As Li and Durgin (2012) point out, the documented cases of divergence from Euclidean principles on a global level do not necessarily imply divergence from Euclidean principles on a local level. Rather, global divergence from Euclidean principles may be caused by local distortions that are consistent with Euclidean principles. Indeed, given the exaggeration of perceived angle of gaze declination by a factor of 1.5, if the geometry of people's experience of egocentric distance is consistent with their angular misperception, the exaggerated perceived gaze declination predicts a linear compression of perceived egocentric distance with a factor of about 0.7 – which is precisely what has been found in various distance estimation studies like Li, Phillips, and Durgin (2011) as stated above.

To summarize, overestimation bias in perceived gaze declination is one possible cause of the well-documented underestimation bias in perceived egocentric distance. People tend to rely on the perceived angle of their gaze declination as a reliable source to infer egocentric distance to a specific point on the ground. The exaggeration of angular declination would make egocentric distances appear condensed, as found across various studies on egocentric distance perception. The question is whether such perceptual bias would be reflected in *verbal* estimates of egocentric distances as well.

Verbal Measurement of Egocentric Distance

As briefly mentioned above when describing the methods used by Gilinsky (1951), some researchers have assumed a direct correlation between nonverbal (i.e., perceptual) estimation and verbal estimation of egocentric distances. Through the nonverbal estimation data summarized above, I have demonstrated that egocentric distance is normally perceived linearly but inaccurately (i.e., compressed). The question is whether verbal estimates of egocentric distance would show the same pattern. Before reviewing studies on verbal estimation of distance, it is worth clarifying that there are two main types of verbal measurement that have been used. One is direct estimation of ground distances in standard units like feet, meters, or yards. The other is magnitude estimation using arbitrary units.

Studies of verbal estimation of distance have generally found that both direct and magnitude estimates are indeed consistent with nonverbal estimates. Specifically, just like nonverbal estimates examined in the previous section, participants' verbal estimates are proportional to actual distances with an exponent very close to 1. Also just like nonverbal estimates, verbal estimates show the underestimation bias of egocentric distance. That is, verbal reports typically underestimate egocentric factors by a factor between 0.7 and 0.9 (Da Silva, 1985; Loomis & Philbeck, 2008). Such linear compression of egocentric distances is again consistent with the angular expansion hypothesis (Durgin & Li, 2011). Nevertheless, it is also noteworthy that the ratio of underestimation for verbal estimation ranges from 0.7 to as high as 0.9. I will return to the topic of individual differences in the accuracy of verbal estimation in the later sections. For now, it is sufficient to say that both nonverbal and verbal estimates of egocentric distance support that perceived distance is compressed in a linear fashion, which is consistent with the angular expansion model (Durgin & Li, 2011). Interestingly, some researchers have critiqued the verbal measures of distance, arguing, for example, that the underestimation bias found in verbal estimates may be a mere result of judgmental scaling artifact.

Responses to the Critiques of Verbal Measures

One of the most prominent critiques of verbal measures comes from a group of researchers who utilize action measures to study estimation of egocentric distance. Action measures require participants to directly act on the environment, with the purpose of demonstrating their perception through action. For instance, Loomis et al. (1992) asked their participants to walk toward a previewed target while blindfolded, so as to examine the participants' distance estimation ability. Perhaps surprisingly, Loomis et al. (1992) found that walking to the target without visual feedback was fairly accurate, even at a distance as sizable as 20m. If egocentric distances are systematically underestimated, then how can one explain such accuracy in motor performance? It is through this rationale that some researchers have argued that there is in fact no error in the perception of egocentric distance.

Interestingly, Li, Phillips, and Durgin (2011), the group of researchers who proposed the angular expansion theory, suggested that there is a way to reconcile their findings of compressed egocentric distance with accurate motor performance. Rather than assuming that there are two different systems operating for perception and for action, Li, Phillips, and Durgin (2011) argued that actions like walking are accurate because of a continuous calibration process, despite the underlying bias in perception. In other words, the fact that observers view 10m ground distance as 7m long does not make the observers unable to reach a target that is 10m away; rather, the observers calibrate their stride lengths to be 70% of the actual length. Because self-motion is continually calibrated based on the visual feedback, motor estimates appear correct even though verbal and perceptual estimates are actually inaccurate. Following the authors' term, I will call this proposal the locomotor calibration theory.

What is also interesting is that in Loomis et al. (1992), when asked to walk a frontal extent without visual feedback, participants walked much too far. The fact that the egocentric distance was walked accurately and yet the frontal distance was overshot adds support to the locomotor calibration theory. The perceived egocentric distance is compressed, and because walking is exclusively based on egocentric distance in daily life, walking is calibrated to this compressed perception. When suddenly made to walk based on frontal extents, people make mistakes.

Connecting Perception with Action: Perceptual Matching Tasks

Notably, even though action measures are not the best method to capture the perceptual distortion because of the corrective calibration process involved in self-motion, it is important to have some type of nonverbal method for measuring perceived egocentric distance. This is because verbal estimates are affected by a variety of cognitive and social factors that may be difficult to disentangle from the analysis of distance perception. This is why the visual matching tasks like that used in Li, Phillips, and Durgin (2011) can be particularly useful. Matching tasks are action-based, in a sense that participants are asked to physically move themselves such that their distances from a particular target match a frontal or vertical extent. At the same time, unlike pure action measures, matching tasks can reflect the perceptual bias because participants are asked to match egocentric distance to a specific length rather than to directly act on that distance. If the locomotor calibration theory were correct, then matching tasks should show the compressed perception of egocentric distances.

As one example of visual matching tasks, Purdy and Gibson (1955) had their participants bisect or trisect large egocentric distances. Participants could accomplish this task fairly accurate. What this demonstrates is that, again refuting the hyperbolic model (Gilinsky, 1951) and supporting the angular expansion hypothesis (Durgin & Li, 2011), perception of egocentric distances is compressed but not compressive. However, given the nature of the fractionation experiment, Purdy and Gibson (1955) could not identify the scale with which the participants were perceiving egocentric distances. Li, Phillips, and Durgin (2011) found a way to demonstrate the magnitude of perceived egocentric distances, by having their participants compare frontal or vertical extents with egocentric extents. In this novel visual matching task, observers were asked to adjust their egocentric distance from one experimenter until the distance appeared equal to the frontal extent between the first experimenter and another experimenter. As expected from the angular expansion hypothesis, participants set themselves much too far away from the first experimenter, suggesting that their perception of depth intervals is compressed relative to their perception of frontal intervals. Specifically, the average ratio of actual distance to height was 1.5, consistent with the prediction of the angular expansion theory that the distance perception is compressed by a factor of 0.7 (Higashiyama & Ueyama, 1988; Li, Phillips, & Durgin, 2011). The fact that participants in Li, Phillips, and Durgin (2011) demonstrated the underestimation bias also supports the locomotor calibration theory in that accurate self-motions do not result from correct perception but from continual calibration.

Yet another example of matching task comes from Li et al. (2013), in which participants directed the experimenter to put a cone on the ground closer or farther, until they felt that their distance to the cone was same as the distance between two other cones next to them. In addition to this visual matching task, the participants walked previewed egocentric or frontal extents while blindfolded. On both matching and walking tasks, frontal distances were perceived as larger than egocentric distances. The cone was set much too far away from the participants on the matching task, and the frontal extent was overshot on the walking task as was the case in the aforementioned results of Loomis et al. (1992). Therefore, contrary to a claim that the accuracy of self-motion implies lack of perceptual bias in distance estimation, visual matching tasks demonstrate that the perceived egocentric distance is compressed. Self-motion is likely to be accurate because of the calibration process that compensates for the underlying perceptual bias. Because walking is calibrated to compressed egocentric distance, the frontal distance is overshot in the blindfolded walking tests (Loomis et al., 1992; Li et al., 2013).

Two-Systems Theory Versus Locomotor Calibration Theory

One of the implications of the visual matching tasks described above is that action measures do not necessarily capture biases in perception. In other words, effective action does not require unbiased perception. Notably, this axiom can be applied to the case of hill perception as well.

Geographical slant perception is another area of study in which researchers have disagreed about the existence of perceptual biases. On the one hand, verbal reports of the perception of outdoor hills have consistently shown dramatic overestimation of geographical slant (Durgin et al., 2010). In contrast, using palm board adjustment as an action measure, researchers like Proffitt et al. (1995) argued that accurate perceptual representation of hills guides motor actions on hill. To be clear, a palm board is a flat surface that can be rotated around a horizontal axis by hand. Proffitt et al. (1995) found that, compared to the verbal reports of hill slant, slant estimates made by adjusting a palm board were much closer to the true orientation of hill and in fact showed little evidence of slant overestimation (Proffitt et al., 1995).

Based on such apparent discrepancy between haptic and verbal measure of hill slant perception, Proffitt et al. (1995) argued that there were two separate representations for geographical slant. One of these representations would be an accurate motor representation of the hill to guide the accurate motor action, whereas the other would be a biased representation that is available to conscious inspection and verbal reporting (Bhalla & Proffitt, 1999). This two-systems theory appears to be supported by the fact that, in real life, people do not have a difficulty in going up a hill, despite their presumably biased perception of hill slant.

The locomotor calibration theory, in contrast, suggests that effective motor action does not need to be accurately guided (Durgin, 2014). The successful climbing of hills can be easily explained by the fact that people calibrate their movements based on visual feedback. If perceptual bias is stable, effective motor action can be guided by biased perceptual experience. The palm board estimates, however, require an additional explanation, given that palm boards are not a pure action measure. In fact, palm boards are essentially a perceptual matching measure, in that participants are asked to match the orientation of palm board with the orientation of a hill as they see it. Therefore, if perception of hills is biased as has been demonstrated by verbal reports, then palm board estimates should also show the same bias.

How can the locomotor calibration theory explain the fact that palm board estimates were quite close to the true hill orientation in Proffitt et al. (1995)? The answer can be found in Durgin et al. (2010). Through a series of experiments, Durgin et al. (2010) demonstrated that people's perception of palm board orientation is, in fact, biased. According to Durgin et al. (2010), the apparent accuracy of palm board estimates results from poor calibration of wrist flexion. Importantly, wrist-flexion palm board estimates can significantly underestimate the perceived orientation of surfaces (Durgin et al., 2010). Participants in Durgin et al. (2010) provided wrist-flexion palm board estimates that significantly underestimated the orientations of near, reachable surfaces, even though they could fairly accurately match these orientations when they gestured with a free hand. This result was replicated with outdoor hills, suggesting that participants tend to provide palm board estimates that under-report their perception of hill slants. Considering that wrist-flexion palm board measurements tend to significantly underestimate people's perception of hill slants, the seemingly accurate wrist-flexion palm board estimates reported in Proffitt et al.

(1995) in fact point to perceptual overestimation of hill slants.

In sum, both distance and hill slant estimation data are consistent with the locomotor calibration theory (Li, Phillips, & Durgin, 2011). There is little evidence to argue that there are two separate systems in the perception of egocentric distance and geographical slant. Rather, a single biased perceptual representation of distance and hill slant appears to guide both perception and action. The reason why motor action is so accurate and effective is because people adjust their action based on their biased perception. Both perceptual matching data and verbal reports suggest that egocentric distance is systematically underestimated, whereas geographical slant is systematically overestimated. Even though wrist-flexion palm board estimates, one example of perceptual matching tasks, appear to suggest that perception is unbiased, Durgin et al. (2010) demonstrated how noisy and biased wrist-flexion palm board estimates are. In order to examine nonverbal perception of hill slants, it is important to use free hand measure or elbow-flexion palm board estimates instead.

Anti-Geometric Approaches to Explaining Variability in Perceptual Estimation

Thus far, drawing from the framework of the angular expansion theory and the locomotor calibration theory, I have described how the perception of distance and hill slant is normally biased. What I now wish to explain is the individual differences present in verbal estimation of egocentric distances and hill slants. As mentioned in an earlier section, while perception of egocentric distance is normally compressed, some individuals do report higher verbal estimates of distance compared to other individuals. Verbal estimates of hill slants show a wide range of individual variation as well, even though it is generally true that slants are overestimated.

Bhalla and Proffitt (1999), the same researchers who proposed the two-systems theory described above, argued that such individual differences in perceptual estimates result from physiological factors like fatigue. Based on their theory, people have an accurate representation of hills and egocentric extents that is dissociated from conscious judgments including verbal estimation. In order to explain the variability in verbal estimates, Bhalla and Proffitt (1999) proposed a theory that I will refer to as effort theory. Based on the effort theory, perception of slope and distance is directly affected by behavioral potential, which is in turn affected by such variables as physical fatigue, fitness, general health condition, and age. In opposition to the angular expansion hypothesis, the effort theory claims that there are no systematic, geometric biases in perceiving egocentric distances. Rather, according to Bhalla and Proffitt (1999), perception and judgment of egocentric distance are affected by the amount of energy expenditure that individuals expect from the experience of spanning that distance. By the same logic, verbal measures of hill slope can be seen as affected by the amount of energy individuals expect to expend while climbing that hill. Individual level of fitness is also taken into account; in other words, even for the same distance and hill slope, individuals who are less physically fit are expected to provide exaggerated verbal estimates compared to individuals who are more fit.

One clear shortcoming of the effort theory is that it cannot account for data obtained from the aforementioned perceptual matching tasks, which demonstrate perceptual biases that are fairly stable and generally consistent with verbal reports. Nevertheless, it is true that the effort theory gives one possible explanation for individual differences in verbal estimates. For example, Proffitt and his colleagues (e.g., Bhalla & Proffitt, 1999; Proffitt et al., 2003; Proffitt, 2006) have reported that wearing a heavy backpack makes slopes appear steeper and distances appear longer. This backpack study has served as an important piece of evidence for Proffitt (2006) to make a claim that visual judgments are strongly affected by physiological factors that are relevant to action.

Importantly, Durgin et al. (2009) argued that the results from the backpack study could be interpreted as cognitive effects of experimental demand, not as perceptual effects of physiological factors. Durgin et al. (2009) manipulated the amount of experimental demand that participants would feel between conditions. In the high-demand condition, participants were simply told to wear a heavy backpack and judge the slope of an outdoor hill, following the procedures used by Proffitt (2006). On the other hand, in the low-demand condition, a deception was used to provide a plausible explanation for the reason why participants were required to wear a heavy backpack.

By providing a rationale for wearing the backpack, the researchers aimed to reduce the amount of experimental demand that the participants would feel. Specifically, participants in this condition were told that the purpose of the backpack is to carry electromyographic (EMG) equipment, so that they would be persuaded that the backpack is not intended to bias their slope judgments. In order to enhance the false belief that the backpack held EMG equipment, participants had real electrodes attached to their ankles that were connected to the backpack. The experimenters also administered a post-test questionnaire so as to confirm participants in the two conditions held different beliefs about the purpose of the backpack. The backpack effects, in which wearing a heavy backpack makes slopes looks steeper (Proffitt, 2006), were reduced to a non-significant level for the participants in the low-demand condition (Durgin et al., 2009).

It therefore appears that, in Proffitt and colleagues' experiments, the hypotheses were transparent enough for participants to be able to provide verbal estimates that they thought would be consistent with the hypotheses – namely, that physical burden would result in higher esimates of slopes and distances. In Durgin et al. (2009), as expected from the experimenters' hypothesis that the backpack effects reflect attempts to comply with experimental demand characteristics, the highest slope judgments were reported by the participants who could guess that the backpack was intended to alter their slope judgments and who thought that their judgments were affected by the backpack. In contrast, participants in the low-demand condition who were deceived into thinking that the backpack served another purpose provided slope estimates that were no different from those of participants who were not even wearing a backpack. Therefore, the backpack effects appear more likely to be judgmental (i.e., cognitive) biases that result from the social context and experimental demands, rather than perceptual biases that result from the physical demands as was suggested by Proffitt and colleagues.

Rebuttals of the Anti-Geometric Approaches: Cognitive Calibration Hypothesis

As Durgin et al. (2009) demonstrated, experimental demand characteristics offer an alternative explanation for the previously reported effects of experimentally induced physical fatigue on perceptual experience. In other words, it appears that the backpack effects were not due to real changes in perception of distance or slope, but rather due to participants' intentional or unintentional compliance with the apparent hypotheses of the experiments. Notably, the backpack manipulation is not the only way in which Proffitt and colleagues have attempted to manipulate people's physiological potential in order to show its effects on the perception of hill slants. Schnall, Zadra, and Proffitt (2010), for example, claimed that people with a low blood sugar level gave higher estimates of hill slopes. Importantly, Shaffer et al. (2013) showed that this result was also likely due to demand characteristics, rather than the changes in physiological potential.

Nevertheless, there are some differences in verbal estimation of distances and hill slants that cannot be fully accounted for by demand characteristics. For example, one recent study found that the elderly often give higher (i.e., more accurate) estimates of egocentric distance (Bian & Andersen, 2013). These results are especially surprising given the age-related declines that have been found in various sensory, perceptual, and judgmental tasks. Through a series of experiments, Bian and Andersen (2013) demonstrated that older observers indeed judged egocentric distances as longer than younger observers, and that this age effect was not due to an age-related differences in output scaling, the use of eye height information, or the use of ground texture gradient information.

Effort theorists may view the higher distance estimates of the elderly as a piece of evidence supporting their claim that physiological factors like fitness can affect perceptual experience. In this anti-geometric perspective, higher verbal estimates of the elderly reflect true difference in perception. Hence, effort theorists would interpret the age effect by showing that the elderly, who are generally less physically fit, tend to perceive egocentric distances as longer than younger adults do. In contrast, the angular expansion hypothesis (Durgin & Li, 2011) suggests that perceptual bias on egocentric distance exists across the lifespan. A challenge that the angular expansion hypothesis faces then is to explain the age effect on distance estimation, when it assumes that the elderly do not *perceive* distances as differently than do the young.

One way in which to overcome this challenge is to identify a cognitive factor present in the elderly that allows them to compensate for the perceptual bias when making explicit judgments. Durgin et al. (2012) is a notable experiment in that it does precisely this. Specifically, the main cognitive factor that the authors identified and tested was experiential knowledge of distance. Based on their theory, even if perception of egocentric distance remains biased across one's lifespan, repeated experience with standardized distances may serve as a basis for successful cognitive calibration of distance estimation. Notably, the elderly are, by definition, more likely to have had the types of experience that gave them explicit knowledge of distances (e.g., golfing, construction work) at some point in their lives. Therefore, if it were true that people can use cognitive calibration to provide more accurate verbal estimates despite their biased perception, the age effect on verbal estimation of distances can be reconciled with the angular expansion hypothesis (Durgin & Li, 2011).

Available data on perception and judgment suggest that the age effect is indeed likely to be resulting from improved cognitive calibration rather than from inherent perceptual changes. Importantly, when the cognitive calibration hypothesis and the effort theory diverge in their predictions, the data tend to support the former. For example, consider the experiments on verbal estimation of hill slants that took age into account. Given that the elderly are generally less physically fit than the young, the effort theory suggests that the elderly would provide higher hill slope estimates than would the young (Bhalla & Proffitt, 1999). Contrary to this prediction, researchers have actually found that the elderly tend to provide lower (i.e., more accurate) estimates of hill slants (Durgin et al., 2010). The calibration hypothesis can explain this result, using the same logic through which it explains the age effect on distance estimation. That is, on average, the elderly have been exposed to more experiences that gave them explicit knowledge about hill slants (e.g., skiing). The cognitive calibration process would then allow the elderly to give more accurate estimates of hill slopes, even though their perception of hills may still be distorted.

Another set of data that is better explained by the calibration hypothesis than by the effort theory is that on undergraduate athletes' distance estimation. Based on the effort theory, athletes should view egocentric distances as shorter than do non-athletes, given the higher level of physical fitness of the former group. In contrast, based on the calibration hypothesis, athletes should provide higher (i.e., more accurate) estimates of egocentric distances because of standardized knowledge gained from playing particular sports. For example, there is a reason to believe that baseball players have experiential knowledge of distances between the bases and explicit knowledge of the actual dimensions of these distances, and that such knowledge would give them a basis with which to calibrate their explicit estimates of egocentric distances. The results of Durgin et al. (2012) supported the calibration hypothesis, in that athletes provided much higher verbal estimates of egocentric distances. Specifically, even though both athletes and non-athletes were accurate in their verbal estimation of the height of a frontal extent, athletes were significantly more accurate in their estimation of egocentric distances, especially for longer distances.

Perhaps even more importantly, in Durgin et al. (2012), athletes' expert performance in the verbal estimation of distances did not alter their perceptual experience of space. In other words, interestingly enough, athletes' accurate verbal judgment of long egocentric distances did not make them perform any better in a perceptual matching task between the height of frontally viewed poles and the egocentric distances. For non-athletes, their verbal estimates of various distances corresponded to their egocentric distance matches to vertical extents. For athletes, it appears that cognitive calibration allowed them to judge egocentric distances more accurately, but that this calibration was not accompanied by perceptual changes. Simply put, athletes judge distances differently than non-athletes, without seeing them differently. These results hence provide an additional support for the calibration hypothesis over the effort theory, in that accurate explicit judgments do not necessarily need to be accompanied by accurate perception.

In sum, Durgin et al. (2012) demonstrated how perceptual biases for egocentric distances do not differ as a function of athletic experience, even though explicit estimates differ. One important limitation of Durgin et al. (2012), however, was that the perceptual matching task took place in an immersive panoramic virtual environment (VR). Even though the outdoor perceptual matching data parallel the VR data to a large extent (Li et al., 2011), it would be useful to replicate the dissociation between perceptual matching and verbal estimation in the outdoor environment. In fact, this was one of the motivating factors for my research team to design the current study, in which participants performed explicit estimation as well as perceptual matching tasks in an outdoor environment. Moreover, we recruited community members of all ages to participate, in order to examine the effect of general experiential knowledge (as opposed to athletic knowledge specifically) on perception and judgments of egocentric distances. I will describe the motivation for our study in more detail in the following section, before turning to explain the methods of the study.

Motivation for the Current Study

Under the guidance of Durgin, several other undergraduate research assistants and I became involved in designing an outdoor perception experiment during the spring of 2014. We proceeded to run the experiment over the course of the summer and fall of 2014. I will refer to this experiment as Study 1 in the rest of the paper. Our overarching goal for Study 1 was to examine people's perception as well as explicit estimation of egocentric distances, heights, and hill slants.

Specifically for egocentric distances, in keeping with the cognitive calibration theory, we wished to examine whether cognitive calibration was accompanied by perceptual changes. First, we expected to replicate the previous findings that the elderly provide higher (i.e., more accurate) estimates of egocentric distances. Then we wanted to see if this calibration would also be reflected in the perceptual matching task, or if the elderly would perform no differently in the matching task than the young. For this purpose, we requested participants of various ages to make verbal height and distance estimates, and to complete a perceptual matching task between perceived egocentric distances and vertical extents. Furthermore, we administered a series of questionnaires at the end of the experiment that measured participants' experiential knowledge about distances, so as to examine the correlation between the amount of knowledge individuals have and their distance estimates.

With respect to hill slants, our focus was on the gender differences that were previously found in verbal estimation of slants. Even though people of both genders generally overestimate slopes of geographical hills, women tend to give even higher estimates than do men (Durgin et al., 2010). The effort theorists have argued that this result supports their argument that physiological potential affects perception; in other words, because women tend to be less physically fit, they view hills as steeper than do men. In the current study, we wanted to replicate the gender effect in hill slant estimation and then examine what factors other than physiological potential could possibly be contributing to the gender differences. One possible factor is, of course, the gender differences in the amount of experiential and explicit knowledge about hill slants. Another possible factor that has not been considered in previous experiments on hill slant estimation is gender differences in personality. It is possible that women's higher estimates are related to the ways in which they interact with the experimenter in the social context. Notably, the effects of demand characteristics on hill slant estimation found in Durgin et al. (2009) and Shaffer et al. (2013) demonstrate that the social context can have a significant impact on verbal estimation.

Upon finding systematic underestimation of egocentric distances in Study 1, I became curious as to whether there is a developmental trend to this underestimation bias. Durgin and I therefore devised a separate study (i.e., Study 2) in which children of ages between 5 and 10 were asked to do a perceptual matching task. Just as adults did in Study 1, children in Study 2 matched the perceived egocentric distances between a vertical object and themselves on the ground with the perceived height of that object.

Additionally, I also wondered whether children's perception of egocentric distances is related to their developing awareness of size constancy. Children are known to go through notable developmental changes in far-distance size estimation between the ages of 5 and 10 (Kavšek & Granrud, 2009). Kavšek and Granrud (2009), for example, asked children in this age range to judge the size of a standard disc from viewing distances of 6.1m and 61m, by indicating which of the nine nearby comparison discs had the same size as the standard. Five- and 6-year-olds significantly underestimated object sizes at 61m viewing distance, whereas 7- to 10-year-olds made size estimates that were quite accurate and no different from older adults' estimates. Kavšek and Granrud (2009) claimed that this development is cognitive rather than perceptual – in other words, it is not that older children perceive discs differently than do younger children, but that older children have a cognitive capacity to compensate for their perceptual biases.

In another study, Granrud directly tested this metacognitive theory by implementing a questionnaire about size-distance knowledge at the end of the size estimation task (Granrud, 2009). He indeed found that cognitive awareness of the relationship between size and distance, as measured by the size-distance questionnaire, accounted for the age-related changes in size estimation abilities. The effect of age on size estimation abilities was reduced to a non-significant level when size-distance knowledge was added to the analysis (Granrud, 2009). Interestingly, in a later study, Granrud and his colleagues found that a general test of verbal reasoning was a better test of cognition than was the test specific to size-distance knowledge (Merriman, Moore, & Granrud, 2010). For the current study, I decided to implement both types of test in order to see which one is more predictive of size estimation, and possibly of distance perception.

In short, through Study 2, I wanted to replicate the developmental trend in size constancy awareness by using the comparison task that was used in Kavšek & Granrud (2009). I then wanted to have the same children do the aforementioned perceptual matching task for egocentric distances and heights, so as to examine whether size constancy awareness affects distance perception as well. Because I was aiming to see the possible relationship between distance perception and size estimation, I decided to implement the size estimation task at viewing distances of 7m and 20m, rather than 6.1m and 61m used in Kavšek & Granrud (2009). Considering that children viewed vertical extents that were about 12m away from them for the perceptual matching task, it made sense to use distances that were close to 12m in the size estimation task as well. Finally, I wanted to implement metacognitive knowledge tests, in order to see the effects of knowledge on size estimation, as well as on distance perception.

STUDY 1: ADULTS' SPATIAL PERCEPTION AND JUDGMENT

This study investigated the distance and hill slant estimation abilities of adults at or over the age of 18. Based on the previous findings that the elderly give more accurate estimates of distance (Bian & Andersen, 2013), we wished to test whether age has an impact on performance in perceptual matching tasks as well. In our study, we specifically used a height-distance matching task to test perceptual matching (Li, Phillips, & Durgin, 2011). Using a sample of Swarthmore students and members of the surrounding community, we tested both perceptual matching and verbal estimation of ground distance and height.

With respect to hill slant estimation, it has been reported that estimates of hill slant are often higher (i.e., less accurate) for women than for men (Durgin et al., 2010). We sought to examine various factors that might result in sex differences in hill slant estimation, such as personality variables (Agreeableness, Conscientiousness, and Emotional Stability), prior knowledge about hill slant, spatial skills as measured by mental rotation task, as well as demographic variables including participants' height and weight.

Hence, the experiment as a whole had three parts: distance estimation tasks consisting of a height-distance matching task as well as explicit verbal estimation of ground distances, hill slant estimation task, and a computerized survey including personality questionnaires, a mental rotation task, and questions about background knowledge and demographic information. A few predictions were made; first, we expected to find the previously documented age differences for verbal distance estimation and sex differences for slant estimation. More importantly, we hypothesized that such differences would be mediated by differences in background knowledge or personality traits. Specifically, we also expected to find reliable effects of knowledge regarding hill slant on slant estimation and reliable effects of knowledge regarding ground distance on distance estimation. On the other hand, we did not make specific predictions as to which personality variables would have a reliable effect on slant or distance estimation, because, to our knowledge, our study is the first to have explored the possible interactions between knowledge and personality on slant or distance estimation. Finally, in regard to distance estimation, we expected to observe dissociation between the verbal estimation and perceptual matching of distance to height. In other words, we hypothesized that angular scale expansion would manifest across one's lifespan, even if one has acquired specialized knowledge of distance and can give accurate estimates of egocentric distance when reporting verbally.

Method

Participants.

One hundred and six adults (60 female) participated in total. Fifty-eight participants (27 female, age range 18-22) were undergraduate students attending Swarthmore College, whereas 48 participants were residents of the surrounding community (33 female, age range 18-72). Swarthmore students signed up for the study through a research participation website. The non-student participants were recruited in various community events. All participants were greeted in front of the psychology building at Swarthmore College, and given an informed consent form to read and sign. At the end of the experiment, participants received $10 in cash as a compensation for their time. The college research ethics committee approved experimental procedures in all the tasks reported below.

Method for Height-Distance Matching Task.

The Task The experimenters had participants walk forward or backward in an open field until the participants felt that they stood at the same distance away from a pole as the height of that pole. If perception of egocentric distance is compressed across the lifespan, as hypothesized above, participants should position themselves further away from the pole than is necessary. In order to ensure that such errors in matching height to distance result from the perceptual compression of egocentric distance rather than from an erroneous estimation of pole height, at the end of the matching task, we also asked participants to verbally estimate the height of the tallest (7m) pole. By making perceptual matching the first task participants were asked to do, we attempted to obtain nonverbal measurements of perceived egocentric distance that were not contaminated by other tasks.

Materials 3m, 5m, and 7m-long poles were set up on a grassy, level playing field on Swarthmore College campus. Three strings ran along the ground from the base of each pole to the starting position, which was at 15m away from the base of each pole. As a measurement device, a laser range finder was mounted on a tripod that was placed 2m behind the starting position.

Procedure Upon arriving on the field, participants were asked to stand on the starting position for the 7m pole, facing away from the pole. When signaled, the participants turned and walked forward or backward until they felt that they were as far away from the base of the 7m pole as the pole was high. Participants were told that they could adjust back and forth as much as they would like. When the participants indicated they were done adjusting their position, the experimenter used the range finder to measure the remaining distance between the participants and the pole. The measurement was taken at waist level to the nearest millimeter. The same procedure was repeated with 3m pole and with 5m pole, in that order. Participants were not rushed, and they could adopt whichever strategy they wished to use, as long as they stayed alongside the string on the ground that connected the base of the pole to the starting position.

Upon the conclusion of three trials, participants were led back to the starting position for the 7m pole and asked to face away from the pole. When signaled, participants turned around and verbally estimated the height of the pole. We told participants that they can use either feet or meters, depending on which unit they feel more comfortable with. We also asked participants to give the most specific estimate possible, instead of simply using multiples of 5.

Method for Distance Estimation Task.

The Task We had participants verbally estimate ground distances between a reference point and themselves. Based on prior research, we again expected to find an underestimation of egocentric distance. We also expected to find an age effect, such that older participants with more background knowledge about distance estimation would be able to provide more accurate verbal estimates of distances. By comparing participants' performance on the height-distance matching task and the verbal estimation task, we would be able to test our hypothesis that cognitive calibration of distance estimation would not be accompanied by perceptual change. If this were the case, then knowledge should only have a positive effect on verbal estimation.

Materials Black spray paint was used to mark the position on the ground at which participants made distance estimations. Four stakes were placed on the ground in a straight line, with the ground distances from the participant being 6, 8, 10, and 12m, respectively. An experimenter placed an orange sport cone over the stakes to mark the reference point, one at a time. The four distances were presented in a predetermined randomized order.

Procedure On each of the four trials, participants were required to stand at the specified position and turn their back, while the experimenter walked out to place the cone at the target distance. As in height estimation, participants were asked to make the most specific estimates possible in either feet or meters. For each trial, the participants were encouraged to take as much time as possible to make the best estimate they can.

Method for Hill Slant Estimation Task.

The Task Participants were asked to verbally estimate geographical slants of three hills on Swarthmore College campus that were preselected based on their accessibility. The golf cart drive to each hill took less than two minutes. The hills were presented in a fixed order. At the first hill, we employed manual and visual slant matching tasks, as well as verbal estimation task; only verbal estimates were collected at the other two hills. We sought to replicate the previously reported gender differences in slant estimation, while testing for the effects of possible mediating variables such as prior knowledge and personality traits.

Materials The first hill was a pathway that exceeded the eye height of all participants and was slanted at 9°. An orange sport cone was placed at a grassy area near the top of the pathway before participants arrived at the hill. For matching tasks as well as for explicit estimation, participants were asked to look at the cone and provide slant estimates of the part of the hill right next to the cone.

For the manual matching task (i.e., free-hand proprioceptive measure), we prepared a palm board apparatus to provide a baseline from which participants would lift their hand to match the slant of the hill. The apparatus consisted of a wooden surface placed on a tripod that was set at a height of 90cm from the ground. The palm board was above the waist level for all participants, and participants stood to the left of the apparatus at less than an arm's distance away.

There was a piece of foam core attached to the side of the palm board so that participants could not see their hand or the palm board. Additionally, the experimenter secured inclinometer on participants' hand with an elastic band, so as to accurately measure the palm orientation.

For visual slant matching, the researchers created a visual angle measurer. The measurer consisted of two metal rulers attached to an electronic protractor. One of the rulers was fixed at the horizontal (0°) orientation, whereas participants could adjust the other, stationary ruler so as to match the perceived orientation of the hill relative to the horizon. The stationary ruler could be adjusted all the way up to vertical (90°) orientation.

The second hill was a grassy slope that was not a pathway. The vertical height of the hill exceeded the eye height of all participants, and the hill had an average slope of 22.5°. Before participants arrived, a short sport cone was placed at the elevation of 1.5m, which was at or slightly below the eye height of participants. Participants were again instructed to estimate the slant of the hill at the point next to the cone.

The third hill was a pathway whose vertical height was near, but below, the eye height of the participants. The hill had an average slope of 4.5°. Here, instead of placing a cone as a marker, we had preselected a lamppost near the top of the pathway as the reference object. Participants were instructed to look at the base of this lamppost and to estimate the slope of the walkway at that point.

Procedure Upon completing the distance estimation task, participants were driven to the first hill by golf cart. Participants were not told that they were going to be estimating hill slants until they were led to the base of the first hill. When participants were in position (i.e., to the left of the palm board apparatus), they were told that they will be estimating the slant of the hill in three different ways.

First, participants were instructed to place their right hand on the palm board and to stand so that their hand and the palm board were hidden from view. After confirming that the participants could see the orange cone, the experimenter asked participants to look straight ahead at the hill and to focus on the part of the path next to the cone. Participants were then instructed to set their palm to an orientation that felt parallel with the hill. Participants were explicitly told to lift their forearm using their elbow, as opposed to only lifting their hand using their wrist. In order to make sure that the participants understood the instruction, the experimenter demonstrated holding her hand in the air to match the slope of the hill. Participants could take as much time as they wanted before letting the experimenter know that they were done adjusting the position of their hand. At this point, participants were asked to hold their hand in position for a couple of seconds, so that the experimenter could take the measurement off of the inclinometer. Participants were then told to place their palm flat on the palm board again, so that the experimenter can take the baseline reading.

When participants took their hand off the palm board, the experimenter handed them the visual angle measurer. Participants were reminded that their task is to estimate the orientation of the hill at the point next to the cone. The experimenter showed the participants how the device works and emphasized that the stationary ruler can move from 0° to 90°. Participants were encouraged to set the measurer as precisely as possible to match the slope of the hill. Participants were not hurried, and they handed the device back to the experimenter when they felt satisfied.

After recording the result of the visual matching task, the experimenter asked participants to estimate the slant of the hill verbally. Participants were asked to respond in degrees, and were reminded that the horizontal would be 0° and a vertical wall would be 90° steep. Participants were asked to be as precise as possible in their estimate. The procedures for the verbal estimation were repeated for the second and third hill.

The outdoor portion of the experiment as a whole (i.e., height-distance matching, distance estimation, and hill slant estimation tasks) took about 25 minutes. Throughout the outdoor tasks, participants received no feedback about the accuracy of their judgments.

Method for the Indoor Tasks.

The Task The indoor tasks consisted of a brief vision test to ensure that the participants could see the reference points when they were performing the outdoor tasks, and a computerized survey. The survey was administered so as to gain data on participants' personality traits and background knowledge, which we suspected might have mediating effects on slant and distance estimation abilities. In addition, participants did a mental rotation task and provided demographic information.

Materials A standard eye chart was attached to a wall at eye level. We marked the floor with a piece of blue tape, exactly 10 feet away from the chart.

The computerized survey was meant to be self-explanatory, with all the instruction included in the survey, and self-paced, with the exception of the mental rotation task that had specific time limits. Because the survey consisted of several disparate sections, I will explain each section separately below:

(a) Introductory instruction page: Participants were thanked for participating in the study and offered an overview of the survey. Participants were also reminded that they should let the experimenter know if they have any questions or concerns at any point during the survey.

(b) Big Five Inventory (BFI): BFI is a self-report questionnaire designed to measure five personality dimensions: agreeableness, conscientiousness, emotional stability, extraversion, and openness. One of the most widely used instruments of personality assessment, BFI has been repeatedly demonstrated to be a reliable and valid measure of the five personality traits (Goldberg, 1992; John et al., 2008). Out of the five traits, we decided to only test for three traits on which reliable sex differences have been found: agreeableness, conscientiousness, and emotional stability.

The three scales each consisted of 20 one-word personality descriptors to which the participants responded with degree of agreement or disagreement on a 9-point Likert scale. Following the usual protocol for BFI, participants were instructed to describe themselves as they see themselves at the present time, and to compare themselves with other people of the same sex and similar age. For example, for agreeableness, participants were asked to indicate how accurate it would be to describe themselves as "cooperative" on a 9-point scale, compared to other people they know of from the same demographic group as themselves (1: Extremely inaccurate, 3: Quite inaccurate, 5: Neither, 7: Quite accurate, 9: Extremely accurate). Example items for conscientiousness and emotional stability were "efficient" and "relaxed," respectively. Half of the items were reverse-coded for each scale (e.g., "rude" for agreeableness, "negligent" for conscientiousness, and "fearful" for emotional stability). The items across three scales were presented in a randomized order for individual participants. The reported ratings were averaged to create one score per scale for each participant.

(c) Balanced Inventory of Desirable Responding (BIDR): We included this scale as a measure of social desirability. Social desirability is a tendency to misrepresent oneself in order to manage positive self-presentation, instead of responding truthfully (Paulhus, 1991). We were interested in seeing whether such tendency would have an impact on explicit estimation of hill slants or distances. The BIDR questionnaire we used consisted of 40 items for which participants indicated the degree of agreement or disagreement on a 9-point Likert scale (1: Not true, 5: Somewhat true, 9: Very true). Half of the items were self-enhancing statements that are unlikely to be objectively true; agreement with these items suggests a bias for social desirability. For example, one of the items in this category was "I never regret my decisions." The other half of the items was reports of commonplace undesirable behaviors that are likely to have been committed by any individual at some point. The tendency to deny or under-report such undesirable behaviors indicates a bias for social desirability, and therefore, these items were reverse-coded. An example item in this category was "I sometimes tell lies if I have to." The ratings across 40 items were averaged to generate one social desirability score for each participant.

While running the study, it became apparent to us that the BIDR made some participants feel uncomfortable, which subsequently discouraged them from recommending the study to other potential participants. In order to make recruiting process easier, we eliminated the BIDR from the survey in the middle of the data collection phase. To be exact, 76 participants (38 Swarthmore students and 38 civilians) had completed the BIDR when we decided to leave it out. In the preliminary analysis, the BIDR was found to be correlated with other personality traits and did not have an independent effect on any dependent variable of interest. Hence, the data from the BIDR will not be discussed further.

(d) Mental rotation test: Visuospatial ability as measured by mental rotation task produces one of the most consistent sex differences in favor of males. Therefore, there is a possibility that the previously reported sex differences in slant estimation are partly due to sex differences in visuospatial ability. In order to examine this possibility, we administered a mental rotation test in which participants were asked to decide, as quickly as possible, whether two drawn 3-dimensional objects were the same or different. Specifically, we used line drawings of block stimuli as test items, and participants were given up to 10 seconds to decide whether each pair of objects was the same object rotated to different viewing angles, or mirror images that cannot be mapped onto each other regardless of rotation.

To make sure that participants understood this direction, we included four practice trials in the beginning. For these four trials, participants received automated feedback on the accuracy of their judgment. Alternatively, if they had not responded in 10 seconds, "No response detected" message was displayed on the screen for one second before the next pair of items was displayed. When the practice trials were over, participants were instructed that feedback to their responses will not be provided anymore. The subsequent mental rotation test consisted of 28 trials. Unknown to the participants, the first four trials out of 28 were still regarded as practice trials, and were not included in data analysis.

Performance on the mental rotation test was calculated in two ways. First, the percentage of correctly responded trials out of 24 real trials was recorded. Additionally, it has been shown that there is a linear relationship between the reaction time to each trial and the degree of rotational difference between the two objects shown. The slope of this linear relationship was also recorded as a measure of visuospatial ability, following the protocol of the existing cognitive literature.

(e) Knowledge questionnaire: Participants answered nine questions about background knowledge they have about distance, height, and hill slant estimation. The first three questions asked whether participants had been part of any activities that might have given them knowledge of distance, slant, and height estimation, respectively. We provided examples of such activities for each question to ensure that individual participants were thinking about similar types of experiences: golf or track and field for distance estimation, skiing for slant estimation, and pole vaulting for height estimation. We did not limit the length or nature of responses that participants could provide. Two independent raters coded responses to these questions on a 5-point scale (1: no experience, 2: very limited or temporary experience, 3: some exposure, 4: in-depth exposure, 5: sufficient experience to have knowledge of distance, slant, or height estimation). The ratings were averaged across two independent raters when there were discrepancies.

The fourth, sixth, and eighth items directly asked for participants' conceptual knowledge concerning distance, slant, and height perception. In other words, we asked whether participants think that people generally overestimate, underestimate, or accurately perceive distances, slants, and heights. The fifth, seventh, and ninth items asked whether participants used any conscious strategies in the outdoor portion of the experiment. If they had attempted to compensate for errors they might have made in the outdoor tasks, they were asked to indicate as such and to explain how. Participants could take as much time as they wanted to type in their answers to each of the nine items.

(f) Demographic questionnaire: Participants provided demographic information that we thought might have an impact on distance or hill slant estimation. Specifically, participants typed in their age, gender, height, weight, as well as the type of shoes they were wearing at the time of the experiment. Finally, participants were asked to provide estimates of their heel height. The last two factors will not be addressed further in this paper, as they did not have an influence on any variable of interest.

Procedure When participants completed the outdoor tasks, they were driven back to the psychology building by a golf cart. Before entering a lab in which we had the survey set up, participants stood in position for the vision test. Participants were asked to read the line of the chart with the smallest letters they could read correctly. The experimenter recorded the number of the lowest line for which participants made one or no error.

Participants were then led into the lab and given a brief overview of the survey. They were reminded of the fact that their individual responses will be kept confidential. The experimenter then waited in the adjoining room until the participants completed the survey. Participants were encouraged to ask for assistance if they had any questions about the survey. When participants indicated that they were finished, the experimenter thanked the participants and debriefed them. The survey usually took about 20 minutes, which meant that the experiment as a whole took about 45 minutes.

Results and Discussion

Based on our initial predictions, there are three main questions that need to be answered. First, can we find the documented underestimation bias for egocentric distances and overestimation bias for hill slants? If so, can we replicate the reported age effect in which the elderly provide more accurate estimates for both egocentric distances and hill slants? Can we also replicate the gender effect on hill slant estimation, in which men provide more accurate (but still exaggerated) estimation of slants? Second, in keeping with the cognitive calibration theory

(Durgin et al., 2012), can these age and gender effects be explained by function of experiential knowledge that individuals have about ground distances and hill slants? Additionally, can personality traits explain some of the gender differences in hill slant estimation? Finally, will biases in perceptual matching between egocentric distance and height differ depending on experiential knowledge? Given that the cognitive calibration process is a judgmental rather than a perceptual one, we expected to find no effect of experiential knowledge (or age) on the height-distance matching task.

In order to answer these questions, I will discuss the results from the two outdoor parts of Study 1 (i.e., distance estimation and hill slant estimation) separately, before turning to examine the implications of these results as a whole.

Results from the Distance Estimation Tasks.

Contrary to our original prediction, there was no effect of age on the verbal estimation of distances. Knowledge, but not age, affected distance estimation. Notably, as expected, neither knowledge nor age affected perceptual matching between height and egocentric distance. Each of these results will be explained in more detail below.

Knowledge Effect on Verbal Estimation of Distances: Although explicit distance estimates were collected last among the distance estimation tasks, we begin by presenting these results first. In part this is because, although there are a great deal of data available on distance estimation, there are only very few studies that focused on the age effect (Bian & Andersen, 2013) or the knowledge effect (Durgin et al., 2012). For the non-student civilians in our sample, we expected to see age effects in distance estimation, but anticipated that these effects would be be due to distance-related knowledge accumulated through life experience. In order to test for this

As expected, there was a reliable interaction between the distance value and knowledge about distance, $t(41) = 2.80$, $p = .0078$. What this means is that those who were involved in activities that gave them distance knowledge (e.g., golfing) showed a relatively small amount of underestimation bias. Among the non-student civilians, 24 people reported no prior knowledge about distance and therefore received a distance knowledge score of 1 out of 5. On average, these people showed an estimate gain of about 0.7m for each 1m increase in actual distance. This gain of 0.7 is consistent with previously measured biases (Loomis & Philbeck, 2008; Li, Phillips, & Durgin, 2011). As was explained earlier, this gain is also consistent with the angular expansion theory (Durgin & Li, 2011; Li et al., 2013). In contrast, 15 people who reported having at least some experiential knowledge about distance (distance knowledge score of 2.5 or higher) showed an estimate gain of 0.87, which implies an effect of knowledge on explicit distance estimation. The regression equations are plotted in Figure 2.

Lack of Age Effect on Verbal Estimation of Distances: Even though we found a reliable interaction between distance knowledge and the distance value, we did not find a reliable interaction between age and the distance value. Moreover, the age effect trended toward the direction that was opposite to what was expected. We categorized 48 adults in our non-student civilian sample into two age groups: 20 younger adults who were less than 40 years old, and 28 older adults who were 40 or older. Younger adults showed an estimate gain of 0.8, whereas older adults showed an estimate gain of 0.68. Hence, younger adults tended to have a higher gain of distance estimates than older adults, and the overall effect of age was less pronounced than the effect of knowledge. The regression equations for age effect are plotted in Figure 3.

knowledge score of 1 and those with score of 2.5 or higher on a scatter plot by age (Figure 4).

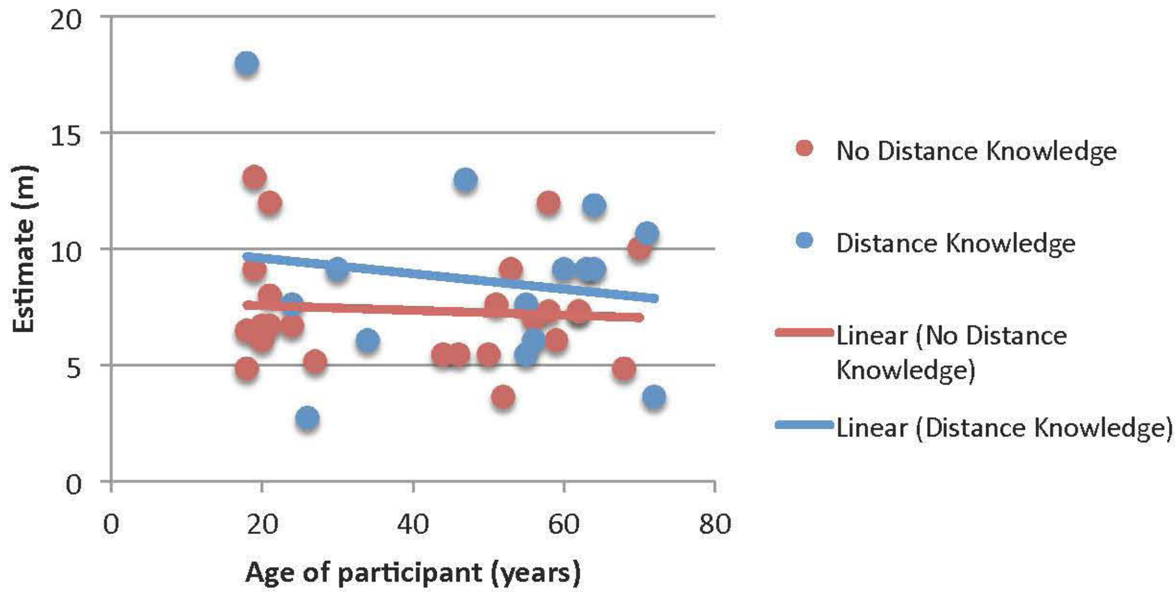

Figure 4. The estimates verbally reported for 10m distance by those with distance knowledge (knowledge score of 2.5 or higher) and those with no distance knowledge (knowledge score of 1). The effect of knowledge on distance estimation appears to be fairly stable and positive across the lifespan. There is only a slight effect of age in which older adults actually tend to be less accurate in their estimation. This reverse age effect may be primarily due to a relatively high estimator who is less than 20 years old and has distance knowledge.

From Figure 4, we can see that, for our sample, the effect of knowledge is fairly stable across the lifespan. Even though there are relatively more participants with distance knowledge among those older than 40, the estimates of older adults with distance knowledge are not so high as to give rise to a positive age effect. On the contrary, there is one young adult with distance knowledge who gave the highest estimation among all participants, which is contributing to the trend of reverse age effect. We therefore conclude that, despite evidence of knowledge effect, we found no evidence of age effect in which older adults provide more accurate estimates (Bian & Andersen, 2013). It appears that, in our sample, older adults did not necessarily have higher amounts of distance knowledge that allowed them to provide higher (i.e., more accurate) estimates.

Body Mass Index (BMI) Effect on Verbal Estimation of Distances: In addition to testing for an age effect, we also examined whether there is a fitness effect on explicit distance estimation. According to the effort theorists' argument that distance perception is affected by factors relevant to behavioral potential (e.g., Bhalla & Proffitt, 1999; Proffitt et al., 2003), those who are less physically fit should perceive *and* judge egocentric distances as longer, compared to those who are more fit. In particular, some researchers have reported that, as predicted by the effort theory, obese individuals provide higher distance estimates because of the increased energetic requirements to walk to a particular target on the ground (Sugovic & Witt, 2011).

As part of the indoor questionnaire, we collected self-reported weight and height. We then computed BMI for each participant. Unlike for age effect, for BMI effect, we examined data from non-student civilians and Swarthmore College students together, because there should be no reason why the effect of BMI on distance estimation would differ between students and non-students.

We found neither effect of BMI on explicit distance estimates nor any interaction between BMI and actual distance values. For example, Figure 5 shows a scatter plot of verbal estimates for 10m distance. Nine of our 106 participants had a BMI in the obese range (30 or higher), but these participants' estimates did not differ significantly from the estimates of those with lower BMI's.

However, we found an interesting effect of BMI when we considered the effects of distance knowledge and BMI together. We used a mixed-effects multiple linear regression with subject as a Random effect. Simply put, it appears that the effect of knowledge is moderated by BMI. The interaction between the distance value and the amount of distance knowledge that we discussed above (Figure 2) was reduced to a non-significant level for participants with BMI below 25. What this means is that there was no or little knowledge effect for participants with normal or below-normal BMI. It is when we examine people with BMI over 25 that we get a strong interaction between the distance value and distance knowledge, $t(31) = 3.392$. Hence, the effect of knowledge on distance estimation was stronger for overweight or obese participants.

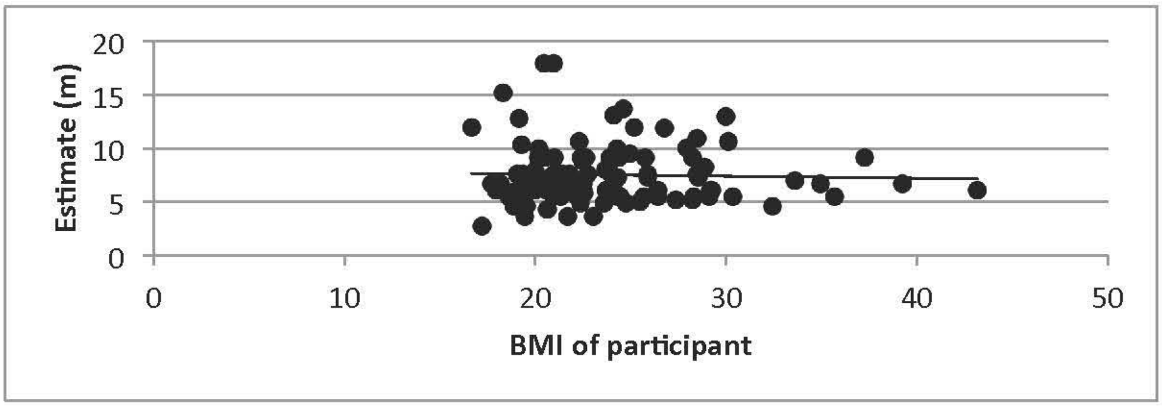

Figure 5. The estimates verbally reported for 10m distance plotted by BMI of participants. There is a negligible effect of BMI on distance estimation, and in fact, those with high BMI tend to provide lower distance estimates, which contradicts the prediction of the effort theory (Proffitt et al., 2003).

In short, contrary to the prediction of the effort hypothesis, it is not the case that less fit individuals necessarily judge egocentric distances as longer. Rather, among those with high BMI, the amount of distance knowledge matters more, such that overweight or obese individuals *with* distance knowledge provide significantly more accurate (i.e., longer) estimates of egocentric distances compared to overweight or obese individuals without distance knowledge. Therefore, it appears that the previously reported BMI effects on distance estimation (Sugovic & Witt, 2011) result from the moderated effect of knowledge, not a main effect of behavioral potential. One way in which to interpret the fact the knowledge effect is stronger for people with above normal BMI is that people use their knowledge more if and when distance matters to their daily lives. It is possible that, for overweight and obese individuals, it is particularly important to take knowledge into account when judging egocentric distances.

Dissociations between Explicit Estimates and Perceptual Matching: Now that we have discussed the results from the verbal distance estimation task, we now wish to focus on the other distance perception task that we had: height-distance matching task. In evaluating the height-distance matching data, we were primarily interested in testing whether individual differences in distance estimation would affect height-distance matching.

To start with the age effect, in our sample, there was no effect of age on the perceptual matching of distance to height. This result is to be expected from the fact that there was no reliable effect of age on the explicit estimation of distances either. There was also no effect of age on verbal estimation of the 7m pole. Across all participants, when asked to match their egocentric distance to the height of three poles, the participants demonstrated an average ratio of the actual distance to height of 1.53 (SE: 0.03). This ratio is consistent with the previous findings (e.g., Higashiyama & Ueyama, 1988; Li, Phillips, & Durgin, 2011), as well as with the idea that angular scale expansion is stable across the lifespan (Durgin & Li, 2011). It is also notable that the verbal distance estimates across all participants averaged about 0.72 (SE: 0.02) of the actual distance. These results are consistent with the geometric model that predicts egocentric distance perception based on the scale expansion in angular variables (Durgin & Li, 2011). The distance to height ratio of 1.53 to 1 that we found in the height-distance matching task can be accounted for by measured biases in perceived direction of gaze declination relative to the horizon (Li et al., 2011).

Perhaps more importantly, even distance knowledge did not affect performance in the perceptual matching task. This result demonstrates that, even though experiential knowledge about ground distances allows one to cognitively calibrate their explicit distance estimates, their distance perception remains compressed. Our finding that knowledge matters for explicit estimation but not for perceptual matching is consistent with the results of Durgin et al. (2012). As was explained previously, Durgin et al. (2012) reported that athletes, who have learned specific ground distances from relevant sports experiences, can give more accurate verbal estimates of far distances compared to non-athletes, but make the same errors as non-athletes when matching perceived egocentric distances to heights. Durgin et al. (2012) and our results support the idea that, unlike explicit estimation of distance, perceptual expansion of scale may be consistent across the lifespan and regardless of the amount of distance-related knowledge. This argument stands in contrast to the effort theory, which suggests that accurate verbal estimates are accompanied by accurate perception (Bhalla & Proffitt, 1999; Proffitt et al., 2003).

In sum, we found evidence of knowledge effect on explicit distance estimation, but did not find evidence of age effect or fitness effect. Based on our data, the effect of BMI is to moderate the effect of knowledge on explicit distance estimation, rather than to bias the actual perception of distance. Moreover, even knowledge only matters for explicit estimation. Perceptual matching of distance to height shows that angular expansion remains, even if one can give fairly accurate distance estimates when reporting verbally. The only other notable influence on distance estimation that we observed was an effect of units used by participants to report the estimates. Specifically, participants who made judgments in meters gave reliably higher estimates than those who made judgments in feet. This unit effect again appears to be a cognitive one rather than a perceptual one, as evidenced by the fact that the choice of units had no effect on the performance in the height-distance matching task.

Results from the Hill Slant Estimation Task.

All three types of measure provided at the first hill were reliably correlated with one another (manual & visual: 0.50; visual & verbal: 0.54; manual & verbal: 0.33), and therefore, the subsequent analysis will only focus on the verbal estimates across three hills. Contrary to our prediction, we did not replicate the gender differences in slant estimation in our study. However, we did find reliable effects of slant knowledge on slant estimation. Conscientiousness, one of the personality traits from BFI, showed an additional effect on slant estimation as well. Each of these results will be examined in detail below.

Knowledge Effect on Verbal Estimation of Hill Slants: Even though we failed to find a reliable gender difference in explicit slant estimation, we found strong effects of knowledge concerning slant. Slant knowledge reliably lowered slant estimates, as would be expected from the cognitive calibration theory. This result also suggests that the lack of gender effect in our data may be primarily due to the lack of gender difference in the amount of knowledge that participants had about hill slants. Swarthmore College is located in a wealthy, well-educated suburban town, in which female adults often have at least as much academic (e.g., engineering) or athletic (e.g., skiing) experience as male adults. The fact that we found a knowledge effect but not a gender effect on hill slant estimation implies that, when there is a gender effect, it may be partly driven by the gender difference in knowledge.

Age Effect on Verbal Estimation of Hill Slants: We also found a reliable trend for slant estimates to decrease (i.e., become more accurate) with increasing age. This finding stands in direct contrast to the effort theory, in that the effort theory would predict an exaggerated slant perception and estimation from the elderly who are less physically fit. As was discussed in Durgin et al. (2010), the age effect on hill slant estimation appears to be more likely an effect of increasing knowledge with age, rather than an effect of decreasing physiological potential.

Personality Effect on Verbal Estimation of Hill Slants: Our motivation for including the personality scales in our indoor questionnaire was to find a variable other than experiential knowledge that can account for the gender differences in hill slant estimation. Notably, in our sample, men and women did not reliably differ in any of the three BFI personality traits examined (i.e., agreeableness, conscientiousness, and emotional stability). It is difficult for us to draw a conclusion about whether any of these personality traits contribute to the gender differences in slant estimation, given that our participants did not show the gender-based personality differences or the gender-based slant estimation differences.

That said, we did find that the effect of knowledge was mediated by conscientiousness, which signifies the degree to which individuals are thorough, careful, or vigilant. Specifically, conscientious people who lacked slant knowledge were more likely to provide higher (i.e., less accurate) slant estimates compared to less conscientious people. On the other hand, conscientious people with slant knowledge were more likely to provide lower (i.e., more accurate) slant estimates compared to less conscientious people. In sum, it appears that conscientious people were more likely to take their knowledge of slant overestimation (or lack thereof) into account when estimating slants. In the general population, women report a higher level of conscientiousness than men. It is possible that the documented gender difference in slant estimation is partly arising from the conscientious female participants' high estimates, assuming that the majority of participants tend to lack experiential knowledge about hill slants.

General Discussion of Study 1

We did not find the previously documented age differences for verbal distance estimation and gender differences for slant estimation. Nevertheless, we found reliable effects of distance-related knowledge on distance estimation and reliable effects of slant-related knowledge on slant estimation. In our particular sample, the knowledge effect did not lead to the age effect in distance estimation, nor did it lead to the gender effect in hill slant estimation. Also importantly, perceptual matching task between distance and height shows that perceived egocentric distance remains biased, even for those with distance-related knowledge. Neither knowledge nor age affected height-distance matching.

STUDY 2: Children's Understanding of Similarities and Perception of Distance and Size

The second study investigated the distance and size estimation abilities of five- to ten-year-old children. The experiment consisted of three parts: a height-distance matching task, a size constancy task, and a metacognitive knowledge test that assessed participants' metacognitive understanding of distance and size perception. Specifically, the metacognitive test consisted of WISC-III Similarities subtest that assesses children's general verbal reasoning (Merriman, Moore, & Granrud, 2010), an abbreviated version of "the size-distance knowledge test" developed by Granrud (2009, p. 644), and the egocentric distance knowledge test. The size-distance knowledge test included three out of the original nine items described in Granrud (2009), through which participants were asked about their knowledge regarding the effects of distance on the perceived size and actual size of objects. The egocentric distance knowledge test consisted of two simple questions that examined whether children were aware of the compression of perceived egocentric distances, and whether they used any strategies to compensate for their errors in distance estimation.

Three predictions were made based on the metacognitive theory (Granrud, 2009) and data found in previous studies on the topic. First, I expected children's performance on the metacognitive knowledge test to be positively correlated with their performance on the size constancy task. I did not have a specific prediction, however, regarding which of the two tests of metacognition (WISC-III Similarities subtest versus the size-distance knowledge test) would be a better predictor of accuracy in size estimation task. Next, I expected older children to perform better on the size constancy task compared to younger children, based on the results found in Granrud (2009) and Merriman, Moore, and Granrud (2010). I also hypothesized that this age difference would be mediated by the difference in the amount of metacognitive knowledge across the age groups. In other words, older children are more likely to have been exposed to experiences that allowed them to understand the effects of distance on size perception. I expected that this advantage in metacognitive understanding, compared to some inherent age-related perceptual development, would better account for older children's higher performance on the size constancy task. If this were the case, metacognitive knowledge would be a stronger predictor of the accuracy in size estimation than age itself. Finally, I predicted that the positive relationship between age and size constancy judgment accuracy would not extend to the accuracy in height-distance matching task. In other words, we expected to see developmental changes on the size constancy task and on the metacognitive knowledge test, but not on the perceptual matching task. Even the oldest children in our sample are unlikely to have had experiences that made them aware of the perceptual compression of egocentric distances. This lack of knowledge can be captured by the egocentric distance knowledge test administered at the end of the experiment.

In fact, even adults are often unaware of their systematic underestimation of egocentric distances, and, as expected, they fail to correct for such bias in distance estimation tasks (Li, Phillips, & Durgin, 2011). Moreover, as described previously, those who demonstrate more accurate verbal scaling of egocentric distance and therefore may be more aware of their underestimation biases (e.g., athletes) still show the same error when given a perceptual matching task (Durgin et al., 2012), implying that perceptual metric of scale is not affected by cognitive calibration of distance. It is therefore unlikely that children in our study would successfully match the height of tall objects to the correct egocentric distance across the age span of five to ten. If it were true that older children do not perform any better on the height-distance matching task than younger children while they perform significantly better on the size constancy task, it would serve as another piece of evidence suggesting that the size estimation ability is not dependent on the accuracy in perception so much as on the development of cognition or metacognition.

Method

Participants.

Twenty-one participants (13 female) were tested in total; seven five-year-olds (three boys and four girls), two six-year-olds (one boy and one girl), two seven-year-olds (two boys), four eight-year-olds (two boys and two girls), five nine-year-olds (five girls), and one ten-year-old (one girl). The participants were recruited from local schools and after-school programs in suburban Pennsylvania. The children's parents were requested to bring their children to Swarthmore College campus at a specific time and day. Upon arrival, the parents were given a written overview of the study and asked to give written informed consent. At the end of the experiment, each participant received a book or a t-shirt as compensation.

Method for Height-Distance Matching Task.

The Task I chose to administer the height-distance matching task before the size constancy task, because the matching task comes first in Study 1 as well. As in Study 1, the matching task measured perceived egocentric distance, by having participants compare the egocentric depth extents along the ground with the vertical extents on the ground. The task consisted of one pretest trial and two test trials. For the test trials, participants viewed a 5.3m-long tree and a 4.7m-long lamppost from a 12m distance, one at a time. Then the participants were asked to adjust their own positions until they felt that their distance from the base of the tree or the lamppost was identical to the height of the object. If participants underestimate the egocentric distances as found in the available literature on adults (e.g., Li, Phillips, & Durgin, 2011), they should position themselves much too far away from the object because of the perceptually compressed egocentric distance. If, on the other hand, participants accurately perceive the egocentric distances, then there should not be a significant difference between their ground distance from the object and the height of the object. In order to ensure that the young participants in Study 2 understood the direction as intended, I used a 2.5m-long road sign for a pretest, as will be detailed in the procedure section.

Materials Target objects were a 5.3-long tree and a 4.7m-long lamppost on a grassy, level playing field on Swarthmore College campus. Participants stood 12m away from the base of each object at the start of each trial. From this starting position, participants were asked to walk forward or backward until they felt that they were as far away from the base of the object as the object was tall. The experimenter used a mobile laser range finder to measure how far away participants were from the base of each object when they indicated that they were done adjusting their position.

Procedure Participants and their parents were greeted by an experimenter at a psychology lab on Swarthmore College campus, and took a 1-minute walk to a lawn on which the height-distance matching task was implemented. One experimenter tested all participants individually in the late morning or early afternoon in the spring. Parents were present at the scene, but they were requested to not influence the participants' responses in any way.

First, participants were asked to stand at a 12m ground distance from a 2.5m-long road sign. The experimenter explained with gestures that, when signaled, the participant should walk toward or away from the sign, until she or he felt that her or his distance from the sign was same as the height of the sign. In order to help the participant understand this direction, a diagram (Figure 6) was shown so as to illustrate how to match the egocentric ground distance from the trunk of the tree with the height of a tree branch. To see whether the child understood the instruction, the experimenter asked where the boy in the diagram (Figure 6) should stand, if he wants to match his ground distance from the tree with the height of the branch. If the child could not provide a correct answer, the experimenter repeated the explanation more slowly and with simpler wordings. Only when the child indicated that the boy should stand much closer to the tree did the experimenter proceed with the pretest.

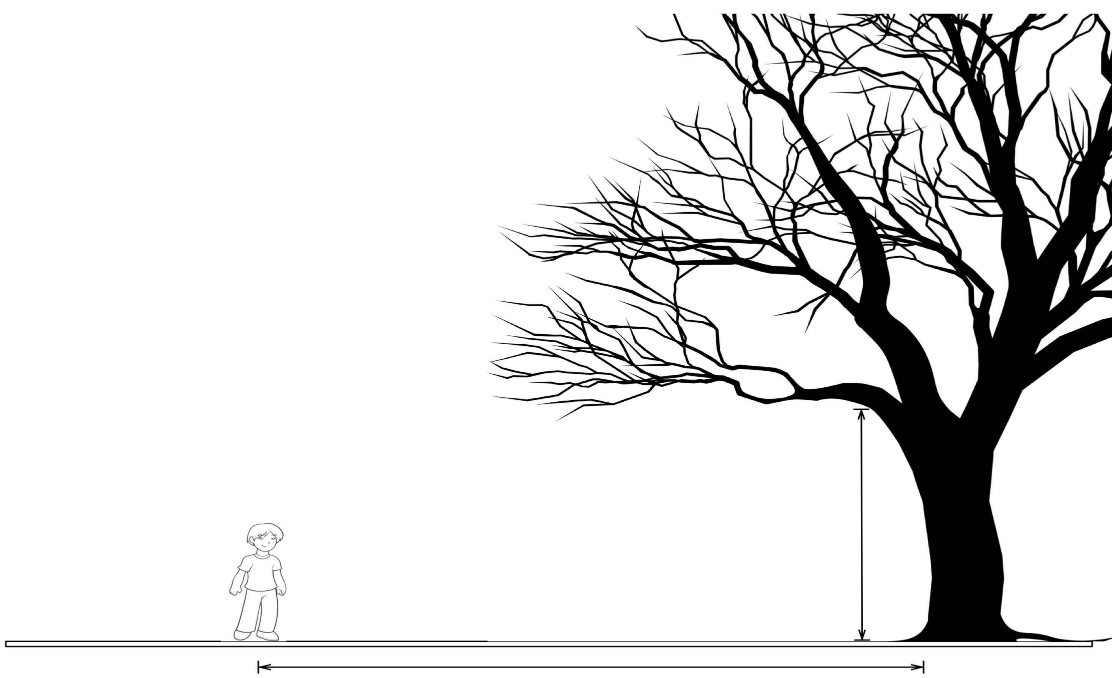

Figure 6. A diagram that was shown to participants in order to confirm their understanding of the height-distance matching task. Using this diagram, the experimenter explained what distance and height mean and what it means to match the distance with the height of a particular object. Only when the participants could correctly answer the question, “So, where should this boy stand if he wants to make the distance between him and the tree the same as the height of this branch?” were the participants deemed eligible for participation.

The child was asked to follow the explained procedure with the road sign. Like in Study 1, participants were told that they can adjust back and forth as much as they wished, and that they should raise their hand when they are done adjusting so that the experimenter can take the measurement. When participants indicated that they were finished adjusting their position, the experimenter used the range finder to measure the objective remaining distance between the participants and the sign. The measurement was taken at participants' waist level to the nearest millimeter. This trial served as a pretest because, for a distance as near as 2.5m, an average observer should not be too far off in their egocentric distance estimation (Li, Phillips, & Durgin, 2011). Only those participants whose final distance from the sign was between 1m and 7m were deemed to have understood the direction and passed the pretest. When participants failed to meet this criterion, they received the verbal instruction one more time with the diagram (Figure 6) and were encouraged to repeat the same procedure. No participant failed the pretest upon the second attempt.

When a participant passed the pretest, she or he was asked to repeat the same matching procedure with the 5.3m tree and 4.7m lamppost, in that order. Participants were not rushed. Unlike in the pretest, the errors were not pointed out in these two test trials. The measurements were again taken at participants' waist level to the nearest millimeter.

Method for Size Constancy Task.

The Task Participants saw a standard object placed 7m or 20m away from themselves and indicated which of the nine comparison objects had the same size as the standard object. The task consisted of three pretest trials and two test trials, using white discs of different sizes as standard objects (Figure 7).

Materials The materials used for this task were the same as those used in Granrud (2009) and in Merriman, Moore, and Granrud (2010). Specifically, the comparison objects were nine white discs made from 1cm-thick foamcore board, and their diameters ranged from 6 to 30 inches (15.24cm to 76.2cm) by increments of 3 inches (7.62cm). Following the procedures of Merriman, Moore, and Granrud (2010), these comparison objects were all placed in a semicircular arc in front of the participants at a 2m distance. The discs were anchored to the ground at a 135-degree angle and arranged in order of increasing diameters from right to left.

Figure 7. A picture of the size constancy stimuli laid out as participants saw them. Participants stood at the end of the pavement with their toes touching the grass. The participants were asked to verbally indicate which of the nine comparison discs that were placed at a 2m distance had the same size as the standard disc placed out in the field. The standard object in the picture is at a 20m distance.

For each of the pretest and test trials, the standard objects stood on the ground with the front surface perpendicular to the ground. For the pretest, three standard objects were presented one at a time. These objects were identical in size to the second, fifth, and eighth smallest comparison objects (22.86cm, 45.72cm, 68.58cm in diameter). For each of the three pretest trials, one standard object was presented directly in front of the participant at a distance of 4m.

For two real test trials, three standard objects could be presented. These objects were identical in size to the fifth, sixth, and seventh smallest comparison objects (45.72cm, 53.34cm, and 60.96cm in diameter), following the procedure of the previous studies (Granrud, 2009; Kavšek & Granrud, 2012). In each of the two test trials, one standard object was randomly selected without replacement and positioned in front of the participants at a distance of either 7m or 20m. The order of the distance at which the standard object was presented was randomized across participants; in other words, about a half of the participants did the 7m trial before the 20m trial, whereas the other half did the 20m trial before the 7m trial.

Procedure The size constancy task was performed on the other side of the same field as the one we used for the height-distance matching task. Upon the conclusion of the height-distance matching task, participants were told that they were going to do a slightly different task from that point onward. The experimenter led the participants to the predetermined starting position for the size constancy task. No moving or stationary landmarks obstructed the participants' view.

The experimenter then directed the participants' attention to the nine comparison objects placed 2m away from them in an arc. For each pretest and test trial, participants were instructed to follow the same procedure: before each trial, the participants turned around so that the standard object could be placed at a predetermined location (i.e., at a 4m distance for the pretest and at a 7m or 20m distance for test trials). When the experimenter walked back to the participants, she instructed them to turn around, view the standard object, and orally indicate which comparison object matched the standard object in size. No time limit was placed on the participants.

All participants were included in the analysis because they could either (a) choose the correct comparison object on at least two of the three pretest trials or, (b) if any incorrect choices were made, the selected comparison object was the one immediately adjacent to the correct comparison object in the array. Only the results from two test trials were used for statistical analysis. In keeping with Granrud (2009), the dependent variable was the percentage error, calculated as the diameter of the selected comparison object minus the diameter of the standard object, divided by the diameter of the standard object, times 100.

Method for Metacognitive Knowledge Test.

The Task After the outdoor tasks, the participants were taken to a lab to complete the metacognitive knowledge test. Three measures were administered so as to examine the extent to which metacognitive knowledge can account for individual children's performance on the height-distance matching task and the size constancy task. The order of the WISC-III and size-distance knowledge test was randomized across participants; the egocentric distance knowledge test always came last.

Materials One measure was WISC-III Similarities subtest (Wechsler, 1991) that assesses verbal induction skill, or the ability to create a general cognitive rule based on the perceptual or functional similarities between different objects. In this test, children are asked to describe ways in which various pairs of objects, such as a wheel and a ball, are similar to each other. Such ability to perceive and verbalize similarities could presumably aid children's performance on the size constancy task, when applied to the similarities between distant and near objects (Merriman, Moore, & Granrud, 2010).

Based on the official scoring criteria for WISC-III, children were scored based on how many word pairs they could correctly explain out of 17 total pairs. The experimenter used a sample response sheet to identify whether to award points for particular responses, and if so, how many points to award. For example, for the aforementioned wheel-ball pair, responses like "Both are round" would receive 1 point, whereas responses like "Both are big" or "Both are small" would receive 0 point. The items are arranged in order of increasing difficulty, and children can receive 1 point for the first four items and up to 2 points for the other 13 items. The test was discontinued after three consecutive failures.

Another measure of metacognition was the size-distance knowledge test (Granrud, 2009). This test measures children's understanding of size constancy more directly than does WISC-III Similarities subtest, by asking children to explain their understanding of the fact that the apparent size is not always the same as the actual size. In order to ensure that participants remain engaged with the task, I decided to only use three out of the nine items that were included in the original test. The excluded items were either redundant with the three items that were used or confusing to some of the participants in previous studies (Merriman, Moore, & Granrud, 2010).

The three items in the abbreviated size-distance knowledge test were presented in the following order to each participant. For item 1, the experimenter held up a stuffed toy animal and asked two questions (in random order): "If I put this far away from you, will it look big to you or will it look little to you?" and "If I put this right up close to your eyes, will it look big to you or will it look little to you?" Participants earned a point only if they answered both questions correctly. The experimenter then asked, "You said that when this toy is far away from you, it will look little to you (or big). When it is far away, is it really and truly little (big), or does it just look little (big?)" and "You said that when this toy is close to you, it will look big to you (or little). When it is close, is it really and truly big (little), or does it just look big (little)?" Again, participants received a point only if they answered both questions correctly. Given that item 1 is based on interaction with a concrete physical object that children are generally familiar with, I thought that it makes sense to present it before the other two items that are based on interpreting unfamiliar photographs.

Items 2 and 3 were presented in a predetermined random order. For item 2, participants saw a photograph of a man sitting with the bottom of one foot very close to the camera so that his foot looked very large. The experimenter first asked participants if the man had "really big foot or normal sized foot," and then asked them to explain their responses. Participants could receive up to 2 points, one for saying that the man actually had normal sized foot, and one for explaining the relationship between perceived size and distance (e.g., "His foot is so close to the camera that it just looks really big."). If the participants said that the man had normal sized foot but provided an explanation that was unrelated to the size-distance relationship (e.g., "If you look at his other foot, you see that it is actually normal sized."), they only received 1 point.

For item 3, participants viewed a photograph of two cars that had equal objective sizes but very different image sizes because of the difference in their distances from the camera. The experimenter asked, "This is a picture of two cars. In real life, are these two cars about the same size or very different sizes?" and then asked participants to explain their answers. Participants received a point for saying that the cars were actually of similar sizes and received another point for mentioning the relationship between distance and perceived size (e.g., "This car just looks smaller because it is farther away."). They only received one point if they knew that the cars were of similar sizes but used a different explanation than the size-distance relationship (e.g., "The cars have same colors and shapes, which means they have same size too!").

Because each of the three items was worth up to 2 points, the maximum possible total score on the size-distance knowledge test was 6 points. The experimenter manually recorded the responses whenever there was any ambiguity as to the scoring.

The last test of metacognitive knowledge was the egocentric distance knowledge test. This brief test consisting of two questions was administered to assess the degree to which children were aware of the perceptual compression of egocentric distance. Children were first asked, "Do you think that people usually see distances as shorter than they actually are, or longer than they actually are? Or do you think that people are usually correct?" Children's responses were coded as either 1: Underestimate, 2: Accurately perceive, or 3: Overestimate. Then children were asked about their strategies in doing the height-distance matching task: "What were you thinking when you were doing the walking test at the beginning, with those poles? Did you use any special trick to get it right?" If participants reported using any strategy other than to just look and walk, their responses were coded as 1; if participants reported no particular strategy, their responses were coded as 0.

Procedure After completing the size constancy task, the experimenter, parent, and the child took a 1 minute walk back to the psychology lab, in which the three types of metacognitive knowledge test were administered. The same experimenter who had conducted the outdoor tasks administered the knowledge test. Children were reassured that some of the questions were designed for much older people, and that they should feel free to skip a question if they do not know the answer. The procedure for Study 2 as a whole took about 30 minutes, with the outdoor portion of the task taking up to 20 minutes.

Results and Discussion

The questions that need to be answered are the following: first, is there an age effect in children's performance on the size constancy task, as was documented in Granrud (2009)? Next, if there is an age effect, then can it be explained by function of the metacognitive knowledge that children have? Based on Merriman, Moore, and Granrud (2010), there is a reason to believe that WISC-III Similarities subtest may be a better predictor of children's performance on the size constancy task than the size-distance knowledge test. Would this be the case in our study? Finally, will the age-related development in size constancy awareness also affect children's performance on the height-distance matching task? The angular expansion hypothesis implies that the distance underestimation bias is stable across the lifespan (Li & Durgin, 2012), but this idea has never been directly tested with children. I will discuss the results from the size constancy task and the height-distance matching task in that order, and then discuss these results as a whole.

Results from the Size Constancy Task.

Considering the importance of participants' exact ages in a developmental study, we used the ages calculated to the decimal from individual children's birth dates to the date that the study was run. Contrary to our original prediction, there was no effect of age on children's performance on the size constancy task. In fact, this performance was not predicted by either age or metacognitive knowledge. On the other hand, as depicted in Figure 8, age was related to performance on the two types of metacognitive knowledge tests related to size estimation: the WISC-III Similarities subtest (Wechsler, 1991) and the size-distance knowledge test (Granrud, 2009).

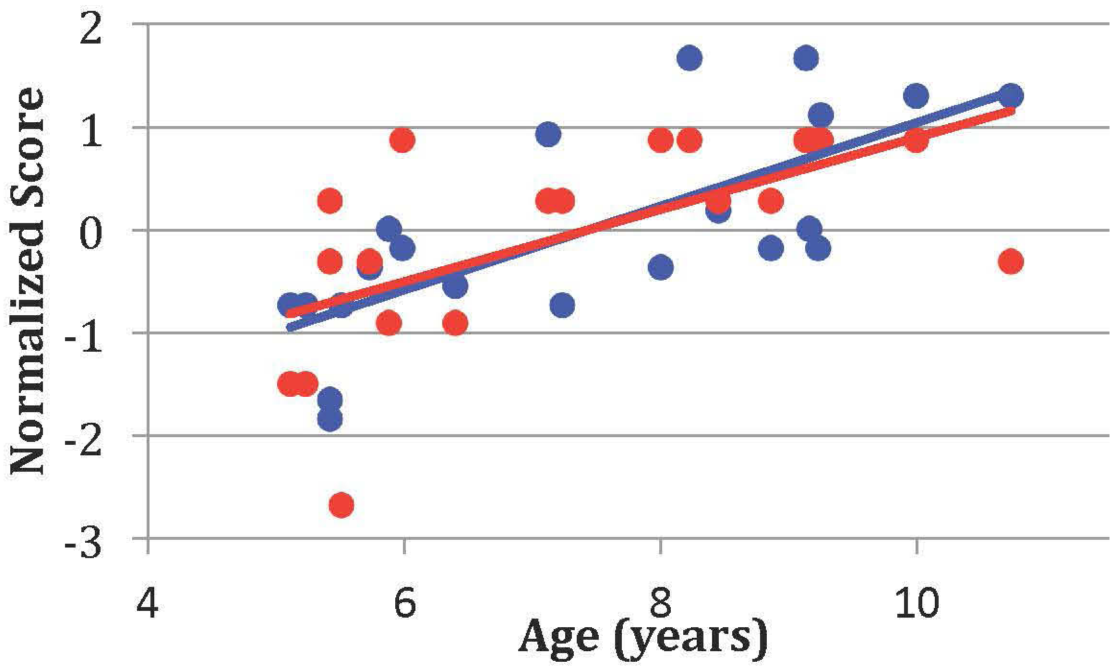

Figure 8. The regression equations demonstrating the positive correlation between age (the x-axis) and the normalized z-scores on the two metacognitive knowledge tests related to size estimation: WISC-III Similarities subtest (blue), and the size-distance knowledge test (red). The linear regression equation for age on the normalized WISC-III Similarities subtest scores is $y = 0.40678 * x - 3.02452$. The linear equation for age on the normalized size-distance knowledge scores is $y = 0.35061 * x - 2.60687$.

Age Effect on Metacognitive Knowledge: Even though our main dependent variable, performance on the size constancy task, was not predicted by age nor by metacognitive knowledge, age itself was strongly positively correlated with the amount of metacognitive knowledge (Figure 8). Children's scores on the WISC subtest and those on the size-distance knowledge test were positively correlated, $r(19) = .439319$, $p < .05$, and age was correlated with both. First, age was strongly positively correlated with children's size-distance knowledge test scores, r(19) = .629946, $p < .005$. What this means is that older children had more explicit knowledge about the relationship between distance and size, as evidenced by the fact that they could articulate that an apparent size of the object is not necessarily same as its actual size.

Moreover, age was also strongly positively correlated with children's WISC-III Similarities score, r(19) = .730871, $p < .005$. The Similarities subtest examines children's ability to form verbal concepts, as evidenced by the fact that they can place objects together in groups that are meaningful from an adult's perspective (Wechsler, 1991). Older children could articulate the higher-order abstract similarities between the named objects (e.g., "a cat and a mouse are both mammals"), rather than focusing on concrete details of these objects (e.g., "a cat and a mouse both have tails"). Presumably, this ability to see the similarities between objects that appear different from each other can help children perform better on the size constancy task (Merriman, Moore, & Granrud, 2010). However, in our sample, even though older children had significantly higher WISC-III Similarities score, they did not perform better in the size constancy task than younger children.

Lack of Age or Knowledge Effect on the Size Constancy Task: Null result like the one we obtained for the size constancy task is, by nature, difficult to interpret. None of the variables of interest that we measured predicted accuracy in the size constancy task. It is possible that the fact that we were not as selective in our pretest criteria as was Granrud (2009) and his colleagues contributed to the lack of reliable age or knowledge effect in our study. Or perhaps we simply did not have enough subjects to see a reliable trend for the size constancy task; Granrud (2009) ran at least 60 participants for each of his studies, whereas we only ran 21 participants. What we can say here is that, older children's knowledge about the relationship between size and distance nor their verbal intelligence allowed them to perform better in the actual size constancy task. The question of what made some of our participants perform better in the size constancy task than others is open to future exploration.

Results from the Height-Distance Matching Task.

We found an unexpected effect of age on the height-distance matching task. Based on the angular expansion hypothesis, we had expected to see a stable bias in perceived egocentric distance across the lifespan. However, there was in fact a reliable correlation of age and performance on the height-distance matching task. In fact, younger children were more accurate in matching their egocentric distances to height than were older children, who tended to show a similar bias as the one adults demonstrated in Study 1.

Age Effect on Height-Distance Matching: As was discussed in the results for Study 1, when performing a height-distance matching task, adults tend to set themselves much too far away from an object because of their compressed perception of egocentric distance. In Study 1 and in other previous studies on height-distance matching, the ratio between the distance at which people set themselves and the height of the object (i.e., distance-to-height ratio) is about 1.5. This ratio is consistent with the idea that the perception of egocentric distance is compressed by a factor of 0.7. The angular expansion hypothesis provides an apt geometric model that can explain this bias in perception through the known exaggerated perception of gaze declination (Li & Durgin, 2012). We wanted to see if the angular expansion hypothesis can be applied to explain children's distance perception as well as adults'.

In order to examine whether children of various ages perform no differently on the height-distance matching task, we analyzed the correlation between age and the distance-to-height ratio. We calculated the latter by dividing the distance at which children set themselves away from the 4.7m-long pole by 4.7m. We decided to focus on the pole rather than the 5.3m-long tree, given that the pole always came after the tree, and children are more likely to have understood the direction when they were doing the perceptual matching task with the pole rather than with the tree.

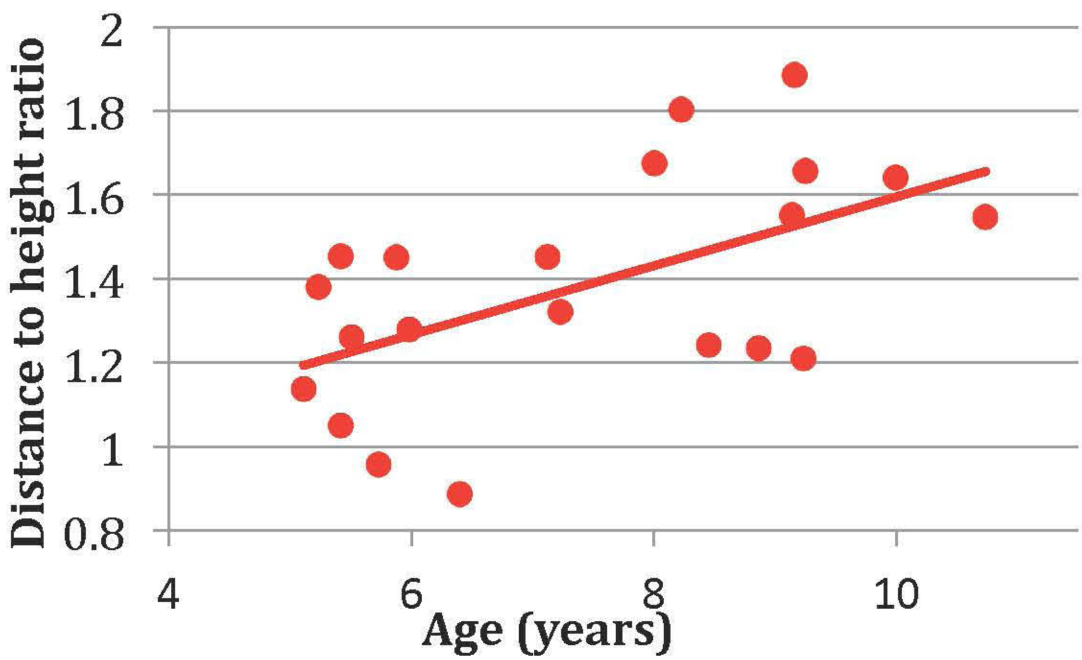

Figure 9. A scatter plot of participants' distance-to-height ratio in the height-distance matching task with the 4.7m-long pole, plotted by age. Younger children are actually more accurate in their matching of egocentric distances to height, as evidenced by the fact that their distance-to-height ratio is closer to 1. On the other hand, older children show higher distance-to-height ratios, reaching adults' typical distance-to-height ratio of 1.5.

Interestingly, in our sample, children's distance-to-height ratio was reliably positively correlated with their age, $r(19) = .552501$, $p < .01$ (Figure 9). In other words, older children set themselves much too far away from the target objects, demonstrating a similar distance underestimation bias as that demonstrated by adults. On the other hand, younger children showed lower distance-to-height ratio, meaning that they matched the same height (4.7m) to shorter egocentric distances. Therefore, younger children were actually more accurate in their matching of egocentric distance to height, whereas older children were less accurate and demonstrated an adult-like underestimation bias of egocentric distance.

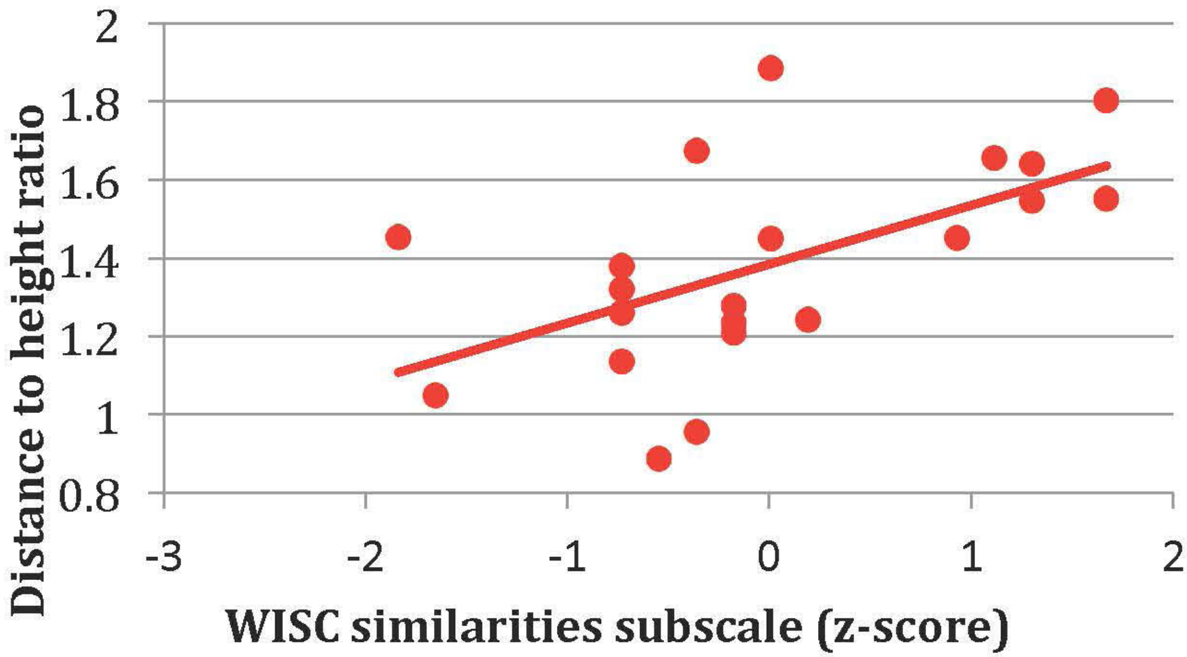

Figure 10. A scatter plot of participants' distance-to-height ratio in the height-distance matching task with the 4.7m-long pole, plotted by normalized z-scores on the WISC-III Similarities subtest (Wechsler, 1991). Children with lower WISC scores are actually more accurate in their matching of egocentric distances to height, as evidenced by the fact that their distance-to-height ratio is closer to 1. On the other hand, children with higher WISC scores show higher distance-to-height ratios, reaching adults' typical distance-to-height ratio of 1.5.

Knowledge Effect on Height-Distance Matching: In order to explain the reason why younger children demonstrate lower distance-to-height ratios, we examined whether there is an effect of knowledge on height-distance matching as well. We in fact found a reliable positive correlation between children's WISC-III Similarities subtest score and their distance-to-height ratio, $r(19) = .563532$, $p < .01$ (Figure 10). This means that more verbally intelligent children set themselves much too far away from the base of the pole, likely because of their compressed perception of egocentric distance. By contrast, less verbally intelligent children as evidenced by lower WISC-

III Similarities subtest scores showed distance-to-height ratios closer to 1, which means that they are more accurate in matching distance to height. The distance-to-height ratio and the size-distance knowledge test score were also positively correlated, r(19) = .493857, $p < .05$. This result demonstrates that those who could articulate the relationship between apparent size and distance were more likely to show an underestimation bias when perceiving ground distance.

General Discussion of Study 2

We were not able to replicate Granrud's finding (2009) of age differences in performance on the size constancy task. Moreover, neither general knowledge as measured by the WISC subtest nor specific knowledge as measured by the size-distance knowledge test predicted performance on the size constancy task. We did find reliable correlations between age and both tests of metacognitive knowledge, however. Our original curiosity about how the developmental improvement in size estimation ability would affect children's distance perception remains unanswered.

With that being said, we found surprising effects of age and of knowledge on the height-distance matching task. This result contrasts sharply with the data from Study 1 on adults, in which neither knowledge nor age affected height-distance matching. For children, it appears that age and knowledge increase the bias in perceived egocentric distances. Does this mean that younger children have unbiased perception of egocentric distances?

There are at least two possible ways in which to explain the lower distance-to-height ratio shown by younger (and less knowledgeable) children. One possibility is that at such young ages as 5 or 6, people do not show angular perceptual exaggeration of gaze declination. In order to test for this possibility, future studies could examine the age-related differences in the perception of angular gaze declination by using similar procedures as those used in Durgin and Li (2011) with participants between the ages of 5 and 10. Perhaps children can correctly perceive the angles of gaze declination, which would mean that their perception of egocentric distance would also be unbiased. How, then, would children grow increasingly worse at matching egocentric distance to height?

It is possible that, as children grow older, they do not adjust their perception of gaze declination based on their increased height. As children grow physically taller, their gaze declination angle would decrease when perceiving the same ground distances. This means that, if their perception of gaze declination does not become adjusted with age, then this lack of adequate adjustment would give rise to the exaggerated perception of angular gaze declination that was documented in the angular expansion hypothesis (Li & Durgin, 2012).

Another possibility is that younger children have not yet learned to use gaze declination as a distance cue. When doing the height-distance matching task, adults and older children tend to immediately think about the relationship between the horizon and the vertical; perhaps younger children see the task as a literal matching of one extent to the other. In fact, in their original proposal that people use gaze declination as a distance cue, Wallach and O'Leary (1982) argued that this distance cue needed to be learned. If the usage of slope of regard as a distance cue is not an innate but a learned phenomenon, then it makes sense that younger children in our sample did not show the distance underestimation bias that results from the angular scale expansion (Li & Durgin, 2012).

GENERAL DISCUSSION

The tasks used to measure perceived egocentric distance have typically been explicit tasks such as verbal estimation. In this case, a primary measure of distance perception is the discrepancy between the reported distance and the actual objective distance. Typically, egocentric distance is underestimated by a factor of about 0.7 (Loomis & Philbeck, 2008), and perceptual matching tasks have demonstrated that this underestimation is a real perceptual bias (Li, Phillips, & Durgin, 2011).

That said, higher estimates have been reported from older participants (Bian & Andersen, 2013) and for those with specialized experiential knowledge (Durgin et al., 2012). Contrary to claims of the effort theory that perception and explicit estimation are both affected by physiological potential, Study 1 found that experiential knowledge related to distance and hill slant is a much more reliable predictor of explicit estimation of distance and slant. Based on Durgin et al. (2012) and our current study, it appears that cognitive calibration is what gives rise to more accurate (i.e., higher) verbal distance estimates from groups like athletes and the elderly, who tend to have more experiential knowledge related to distance. Experiential knowledge provides one with points of reference for judging distance, so that one can correct for the perceptual bias. In our study, the limited number of participants and possible sampling biases contributed to the lack of age effect on distance estimation, but we nevertheless saw a reliable effect of knowledge on explicit distance estimation.

Notably, our measure of distance and slant knowledge was based on distance- or slant-related experiences that were self-reported on a questionnaire administered after the outdoor part of the experiment. It is powerful that, despite possible biases in self-report, we are seeing a reliable knowledge effect on both distance and hill slant estimation.

Additionally, we found that experiential knowledge only affected explicit estimation and did not affect adults' performance in the height-distance matching task. In other words, perception of participants with distance knowledge was not scaled differently than that of participants without distance knowledge, even though the explicit judgments of the former group are calibrated significantly better. The dissociation between explicit estimation and perceptual matching task implies that the use of verbal estimation is susceptible to a wide range of cognitive and social biases. In order to examine underlying perceptual biases, it is important to use nonverbal methods of measuring perceived egocentric distance. Notably, height-distance matching task that we used in our studies is a simple perceptual matching task that can easily capture the biases in perceiving egocentric distance. In addition to using verbal measures of distance estimation, researchers could use methods like height-distance matching task so as to document the dissociation between perception and judgment when it exists.

Another benefit of using the height-distance matching task to examine distance perception is that it allows the researcher to study children who are not yet capable of providing explicit distance estimates. Future research could examine whether the lower distance-to-height ratio found from younger children in Study 2 is resulting from the true lack of bias in distance perception. It is possible that younger children are simply following the instruction in a different way than are older children or adults. On the other hand, it is possible that younger children do not have the same exaggeration bias when perceiving gaze declination, which could result in an unbiased perception of egocentric distances.

References

Bhalla, M. & Proffitt, R. D. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1076-1096.

Bian, Z., & Andersen, G. J. (2013). Aging and the perception of egocentric distance. *Psychology and aging, 28*(3), 813-825.

Da Silva, J. A. (1985). Scales for perceived egocentric distance in a large open field: Comparison of three psychophysical methods. *The American Journal of Psychology, 98,* 119–144.

Durgin, F. H. (2014). Angular scale expansion theory and the misperception of egocentric distance in locomotor space. *Psychology & Neuroscience, 7*(3), 253-260.

Durgin, F. H., Baird, J. A., Greenburg, M., Russell, R., Shaughnessy, K., & Waymouth, S. (2009). Who is being deceived? The experimental demands of wearing a backpack. *Psychonomic Bulletin & Review, 16*(5), 964-969.

Durgin, F. H., Hajnal, A., Li, Z., Tonge, N., & Stigliani, A. (2010). Palm boards are not action measures: An alternative to the two-systems theory of geographical slant perception. *Acta psychologica, 134*(2), 182-197.

Durgin, F. H. & Li, Z. (2011). Perceptual scale expansion: An efficient angular coding strategy for locomotor space. *Attention, Perception, & Psychophysics, 73,* 1856-1870.

Durgin, F. H., Leonard-Solis, K., Masters, O., Schmelz, B., & Li, Z. (2012). Expert performance by athletes in the verbal estimation of spatial extents does not alter their perceptual metric of space. *i-Perception, 3*(5), 357-367.

Gilinsky, A. S. (1951). Perceived size and distance in visual space. *Psychological Review, 58,* 460-482.

Goldberg, L. R. (1992). The development of markers for the Big-Five factor structure. *Psychological assessment, 4*(1), 26-42.

Granrud, C. E. (2009). Development of size constancy in children: A test of the metacognitive theory. *Attention, Perception, & Psychophysics, 71*(3), 644-654.

Higashiyama, A., & Ueyama, E. (1988). The perception of vertical and horizontal distances in outdoor settings. *Perception & Psychophysics, 44*(2), 151-156.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy. *Handbook of Personality: Theory and Research, 3,* 114-158.

Kavšek, M., & Granrud, C. E. (2012). Children's and adults' size estimates at near and far distances: a test of the perceptual learning theory of size constancy development. *i-Perception, 3*(7), 459-466.

Koenderink, J. J., van Doorn, A. J., Kappers, A. M. L., Doumen, M. J. A., & Todd, J. T. (2008). Exocentric pointing in depth. *Vision Research, 48,* 716–723.

Li, Z., & Durgin, F. H. (2010). Perceived slant of binocularly viewed large-scale surfaces: A common model from explicit and implicit measures. *Journal of Vision, 10*(14), 13-16.

Li, Z., & Durgin, F. H. (2012). A comparison of two theories of perceived distance on the ground plane: The angular expansion hypothesis and the intrinsic bias hypothesis. i-*Perception, 3*(5), 368-383.

Li, Z., Phillips, J., & Durgin, F. H. (2011). The underestimation of egocentric distance: Evidence from frontal matching tasks. *Attention, Perception, & Psychophysics, 73*(7), 2205-2217.

Li, Z., Sun, E., Strawser, C. J., Spiegel, A., Klein, B., & Durgin, F. H. (2013). On the anisotropy of perceived ground extents and the interpretation of walked distance as a measure of perception. *Journal of Experimental Psychology: Human Perception and Performance, 39*(2), 477-493.

Loomis, J. M., Da Silva, J. A., Fujita, N., & Fukusima, S. S. (1992). Visual space perception and visual guided action. *Journal of Experimental Psychology. Human Perception and Performance, 18,* 906-921.

Loomis, J. M., & Philbeck, J. W. (2008). Measuring spatial perception with spatial updating and action. In R. L. Klatzsky, B. MacWhinney, and M. Behrmann (eds), *Embodiment, Ego-space, and Action.* New York: Taylor and Francis, 1-43.

Merriman, W. E., Moore, Z., & Granrud, C. E. (2010). Children's strategic compensation for size underconstancy: Dependence on distance and relation to reasoning ability. *Visual Cognition, 18*(2), 296-319.

Paulhus, D. L. (1991). BIDR reference manual for version 6. *Unpublished manuscript, University of British Columbia.*

Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science,1,* 110-122.

Proffitt, D. R., Bhalla, M. Gossweller, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin and Review, 2,* 409-428.

Proffitt, D. R., Stefanucci, J., Banton, T., & Epstein, W. (2003). The role of effort in perceiving distance. *Psychological Science, 14,* 106-112.

Purdy, J., & Gibson, E. J. (1955). Distance judgment by the method of fractionation. *Journal of Experimental Psychology, 50,* 374–380.

Schnall, S., Zadra, J. R., Proffitt, D. R. (2010). Direct evidence for the economy of action: Glucose and the perception of geographical slant. *Perception, 39,* 464–482.

Shaffer, D. M., McManama, E., Swank, C., & Durgin, F. H. (2013). Sugar and space? Not the case: Effects of low blood glucose on slant estimation are mediated by beliefs. *I-Perception, 4*(3), 147-155.

Sugovic, M., & Witt, J. K. (2011). Perception in obesity: Does physical or perceived body size affect perceived distance? *Object Perception, Attention, and Memory (OPAM) 2011 Conference Report, Visual Cognition, 19*(10), 1323-1326.

Wallach, H., & O'Leary, A. (1982). Slope of regard as a distance cue. *Perception & Pscyhophysics, 31,* 145-148.

Wechsler, D. (1991). *WISC-III: Wechsler intelligence scale for children: Manual.* Psychological Corporation.