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The University of Southern Mississippi

THE PERCEPTION OF DISTANCE ON A REAL GEOGRAPHIC SLOPE

by

David Alan Bunch

Abstract of a Dissertation
Submitted to the Graduate School
of the University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

August 2014

ABSTRACT

THE PERCEPTION OF DISTANCE ON A REAL GEOGRAPHIC SLOPE

by David Alan Bunch

August 2014

Ooi, Wu, and He (2001) have shown that for objects resting on flat, horizontal surfaces, those that appear in the lower sector of the visual field are perceived as close to the observer and objects located near the visual horizon are perceived as further from the observer. Researchers have hypothesized that observers utilize the angle subtended between the horizon and the line of sight to the target object as information for distance. In a previous investigation Hajnal, Bunch, and Kelty-Stephen (2014) showed that an object's physical angle of declination below the horizon is not uniquely utilized when making distance estimates to objects placed on a sloped surface. In that experiment a flat, horizontal surface was visible in the background when viewing objects placed on the sloped surface. To further investigate the possible utility of the angular declination below the horizon hypothesis we have replicated the findings of the previous study on a natural hillside where a flat, horizontal surface is not visible in the background. This setup has allowed us to evaluate whether observers rely on the same information to perceive distance on ramps versus real hills. The present research may have implications for the hypothesis which claims that perceived effort influences space perception (Proffitt, 2006a, 2006b) in addition to optical variables.

The University of Southern Mississippi

THE PERCEPTION OF DISTANCE ON A REAL GEOGRAPHIC SLOPE

by

David Alan Bunch

A Dissertation
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

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INTRODUCTION

On January 15th, 2009, as both of his engines failed after a mid-air collision with a flock of Canadian geese, Capt. Chesley B. "Sully" Sullenberger had a decision to make: where to crash-land his Airbus A320-214 (msnbc, 2009). His first choice would have been to turn the plane around and make a hard landing back at LaGuardia Airport in New York where they had taken off merely 3 minutes prior. However, it was apparent to Capt. Sullenberger that the distance would be too great given the plane's altitude and wind speed. His second option would be to attempt to proceed into New Jersey to make a landing at Teterboro Airport. Yet again, Capt. Sullenberger judged the distance too great given his circumstances. He, therefore, was forced to land the plane in the frigid waters of the Hudson River. Miraculously, all 155 people onboard survived the water landing. This incident became known as the "Miracle on the Hudson."

Aside from his training as a pilot in routine flight procedures as well as emergency procedures, Capt. Sullenberger was able to safely land his plane because nature had provided him with a visual system capable of determining distance with relative accuracy. It was largely due to this ability that Sullenberger decided not to attempt a landing at either of the airports in the near vicinity because of the possibility that his plane would not cover the distance required and would, instead, land in the densely populated areas surrounding both airports, resulting in a massive loss of life (msnbc, 2009). In addition, Capt. Sullenberger's ability to determine distance was again required when attempting to position the plane so that it would strike the water at the proper angle and time so as to keep the plane on top of the water after landing. Without

Capt. Sullenberger's ability to accurately determine distance this incident could have had a completely different outcome, possibly resulting in the title "Disaster on the Hudson."

In less dramatic fashion, but no less important, humans engage in a variety of daily activities which require the ability to accurately estimate distance. For example, when driving a car one must be vigilant in maintaining a proper following distance from the car ahead lest one risk rear-ending the lead vehicle. Also, motorists often have to avoid road hazards (e.g., potholes, shredded tires, road-kill, etc.) and sometimes pedestrians (e.g., children playing near a road). Even in leisure activities it is vital to be able to determine distance effectively. Without the ability to determine distance we could not play most, if not all, sports. Any quarterback worth his salt must have the ability to gauge the distance between himself and his receivers downfield. A flaw in his judgment here could be the difference between a game-winning touchdown pass and a season ending interception. Likewise, our hunter-gatherer ancestors required the ability to accurately determine distance in their hunting pursuits. Without the ability to gauge the distance from themselves to the animal being hunted, they would not be able to accurately hurl their spear or find their target with the tip of a launched arrow.

Perceptual psychologists and vision scientists have long puzzled over the human ability to perceive distance and other spatial properties of the environment. Within the last half-century the two most empirically evaluated theories of visual perception have been the traditional "Air" theory, and the "Ground" theory (Gibson, 1950). In its most fundamental form the "Air" theory of visual perception assumes that perceptual space is a space described by properties of Euclidean geometry such as lines, points, and angles couched in an abstract idealized coordinate system. As such the perception of space and its characteristics such as size, shape, distance, and slope are all expressed in extrinsic units of measurement that have very little to do with the observer. However, our everyday experience of space is not of abstract lines and points. Instead it is a space that is built out of a complex nested structure of layers of surfaces, texture gradients, and patterns of reflected ambient light scattered and cast as complex shadows and optical discontinuities (such as edges). James Gibson (1950) believed that the pattern of reflected light created by the environment contains all of the information necessary to determine the relevant properties of objects within the visual field. Thus, information about depth and distance are carried within the pattern of light that reaches the retina, such that the information lawfully specifies separate surface structures nested within one another, each ultimately understood in relation to their position relative to a solid ground surface on which the observer, in this case the human observer, spends most of his or her time. For Gibson (1950), the ground plane was the starting point of terrestrial visual perception, without which distance perception would be next to impossible. The following empirical investigation, and those from which it is derived, largely utilize Gibson's (1950) "Ground" theory as the theoretical framework.

It has been well established that human observers can accurately judge the absolute ground distance to objects up to 20 m on flat, horizontal terrain (e.g. Loomis, DaSilva, Fujita, & Fukusima, 1992; Loomis, DaSilva, Philbeck, & Fukusima, 1996; Rieser, Ashmead, Talor, & Youngquist, 1990; Sinai, Ooi, & He, 1998; Thomson, 1983). However, researchers are uncertain as to what visual information observers utilize to perceive distance. In addition, little is known about the perceptual abilities of humans to accurately judge the absolute distance to objects on inclined surfaces (e.g. a traffic sign located on a hilly road).

Armed with the basic principles of "Ground Theory," Wu, He, and Ooi (2007) formulated the Sequential-Surface-Integration-Process hypothesis (SSIP) in an attempt to explain visual perception. This hypothesis focuses heavily on the importance of the ground surface as the starting point of distance perception by demonstrating that disruptions in a continuous ground surface (e.g., a gap, a wall, or changes in texture gradient) disrupt distance perceptions. Wu and colleagues (2007) speculated that the visual system integrates visual information in sequential fashion beginning nearest the observer, where information is rich and detailed, and then proceeding towards the visual horizon thus scaling object distance in space. Sinai et al. (1998) have demonstrated that terrain features influence the perception of distance such that gaps in a horizontal ground surface, for example a trench or ditch, cause overestimates of target distance. In addition, they showed that observers underestimate the absolute distance to target objects when viewed across two distinct texture surfaces, but not when the surface is of one unified texture (Sinai et al., 1998). Taken together, these studies indicate that the visual system may utilize the ground surface as a frame of reference for judging absolute distance, and that disruptions of the ground surface texture gradient, such as gaps or differing texture gradients, can lead to inaccurate distance judgments.

According to the SSIP hypothesis, the visual system has to start integrating information about distance anew at the location of ground surface discontinuity. The reason for this, according to Wu et al. (2007), is that there exists an intrinsic bias within the visual system wherein breaks of texture gradient along the ground surface produce the illusion that the far ground surface is slanted upwards when, in fact, it is level with the near ground surface. Wu et al. (2007) have demonstrated this by asking observers to match the orientation of the horizontal near ground surface with a distant portion of the ground beyond a texture boundary. Under such circumstances, observers perceived the two surfaces as coplanar when the far ground surface was tilted downward, presumably compensating for the perceptual bias that causes distant parts of the ground surface to appear slanted upwards.

In light of their findings, Ooi et al. (2001) have proposed that an object's angular declination below the horizon may serve as information for distance perception. According to the Angular Declination Below the Horizon Hypothesis (ADBH), objects which appear lower in the field of view will be perceived closer to the observer than objects located near the visual horizon. Therefore, objects that create large angles of declination below the visual horizon will be perceived as being closer to the observer than objects whose placement near the horizon produces smaller angles of declination. This forms a trigonometric relationship (see Figure 1)

$$d = h/\tan(\alpha)$$

where d refers to the absolute distance to the object, h corresponds to the observer's eye height, and α is the physical angle of declination below the horizon (ADBH) corresponding to the location of the target object's base.

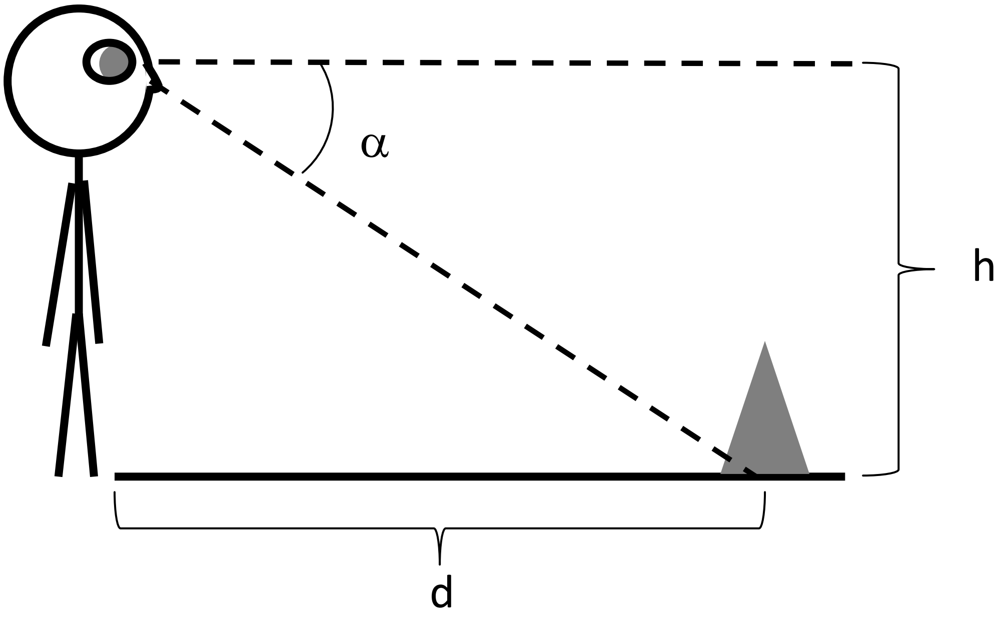

Figure 1. The angular declination hypothesis as applied to targets on horizontal ground.

It is assumed that eye height is a constant and implicitly known quantity that can be utilized by observers in making distance estimates. To determine whether or not eye height had any effect on distance perception, Sinai et al. (1998) had participants make distance estimates to objects located on the ground while standing on an elevated surface. They discovered that manipulating eye height disrupted accuracy in distance perception. However, when asked to estimate their eye height in relation to both their feet and to the ground, as well as provide an estimate of the distance from their feet to the ground, participants overestimated the distance from their feet to the ground and the distance from their eyes to the lower ground; however, they were remarkably accurate in estimating the distance between their eyes and their feet, that is, eye height. This finding suggests that eye height may be utilized as an implicit, internalized measurement standard, a “yardstick” of sorts that is both constant and unique to each observer. Sinai et al.’s (1998) findings provide support for other studies that have come to roughly the same conclusion (Mark, 1987; Sedgwick, 1983; Warren & Whang, 1987) with regard to the influence of eye height on visual perception. Thus, perceived eye height appears to be a crucial, naturally available parameter useful for distance judgments (see Ooi et al., 2001, and Stoper and Cohen, 1986, for further empirical evidence).

A second, vital assumption of the ADBH hypothesis is that any given observer's eye height must approximate the true horizon. In support of this, Sedgwick (1983) has shown that regardless of where one stands (e.g. on an elevated platform, laying down, sitting, or standing straight up) the horizon remains in the same relative position of the visual field. Sedgwick (1973, 1980; also see Wraga, 1999) has also demonstrated that objects which appear to split the horizon are judged to be taller than the observer because in order to do so, they must be located at a height that is greater than the observer's eye level and, thus, their perception of the horizon.

To demonstrate the value of an object's angular declination below the horizon as a source of distance information Ooi et al. (2001) sought to directly manipulate a perceiver's perception of the horizon by using a pair of base-up prisms to induce an increase in the perceived angular declination below the horizon. Participants in this study were required to don the prisms and then provide estimates of the absolute distance to the target objects located on a flat, horizontal surface. Participant estimates undershot the actual distance to the target, presumably because the object's angle of declination was greater than it truly was, which resulted in the perception that the object was closer to the observer. Afterwards, the participants were adapted to the prisms by engaging in a beanbag throwing task for 20 minutes. After this adaptation period in which they were calibrated to the prisms, the participants took off the prisms and then estimated the distance of another target object. As expected, participants overestimated the actual distance to the target, presumably because the removal of the prisms after adaptation resulted in a shift of the participant’s perceived eye level such that the new, adapted eye level (corresponding to the perceived horizon level) decreased from their true eye level, resulting in a smaller angular declination below the horizon and, thus, overestimates of target distance.

Taken together, the previous studies support the assumption that the visual system may utilize an object’s angle of declination below the horizon as an informational source for determining the absolute distance of an object from the observer. However, thus far these investigations have only been conducted in regard to the determination of absolute ground distances to objects on flat, horizontal surfaces. Until recently, it was unknown if this hypothesis also applied to objects located on geographical slopes.

Generalization of the Angular Declination Below the Horizon Hypothesis

Because the ground surfaces of our world are often composed of differing textures, materials, slope orientation, and the like, often even within near-space (2-3 m), it is necessary that visual perception be studied in situations that resemble real-world scenarios. Geographic slopes, which one encounters on a daily basis, offer an exemplary spatial layout with which to investigate the utility of the ADBH hypothesis because slopes alter the visual position of any object relative to the visual horizon. Taken by itself, the ADBH hypothesis would suggest that objects viewed on geographic slopes would induce overestimates of object distance because any object on a slope would rest closer to the horizon, and therefore be perceived further from the observer, than the same object at the same ground distance placed on a flat, horizontal ground surface. However, because we encounter sloped surfaces on a daily basis it is not probable that observers would overestimate the distance to objects on sloped surfaces because to do so would be maladaptive. In addition, objects on sloped surfaces would actually be in closer proximity to the eyes than they would if resting on a horizontal ground surface and may, therefore, be perceived as closer to the observer (for instance, if familiar size and retinal image size are more powerful informational sources in the optic array).

As an informational variable, an object's ADBH holds promise for providing the visual system with information about the environment which is stable and non-changing across viewing conditions. As an approach, ecological psychology (Gibson, 1979), from which the ADBH hypothesis is derived, seeks to discover information within the optic array that is invariant across transformations within the environment. The property of invariance is essential because it provides a perceptual system the ability to reliably detect environmental properties that are integral and informative to the goals of the organism. For vision, these invariants exist within the information carried in the ambient light reflected from objects viewed in the optic array. Due to the physical properties of objects in the environment the patterns of light received by the observer will contain information that is stable and unchanging regardless of transformations to the optic pattern. For example, turning one's head while looking at a rigid sloped surface will alter the pattern of light detected by the visual system; however, the information gleaned from the light patterns (i.e., the texture of the surface, the opacity of the surface, the perspective structure of the surface) will remain unchanged despite the transformations in its pattern across the retina. In fact, moving one's gaze across a surface likely enhances our perceptions regarding object properties (e.g., looking over a ramp from different angles likely confirms perceptions of its rigidity as opposed to one quick static glance).

These visual regularities, or invariants, provide an organism with stable and reliable information about what the environmental object can be used for. For example, the rigid sloped surface previously mentioned may afford a wheelchair-bound individual access to a building built on a raised platform.

For investigators of distance perception the goal is to discover an environmental informational source that is bodily scaled and which remains unchanged, or invariant, regardless of transformations in the optic structure of the object viewed. This research strategy conceptualizes perception as a single-valued function of the information present in the optic array (Turvey, Shaw, Reed, & Mace, 1981). It may be the case that Ooi et al.'s (2001) angular declination below the horizon provides just such an invariant to the perceiver when attempting to discern object distance. However, because the visible horizon is no longer parallel to a ground surface when viewing objects placed on sloped surfaces, the angle of declination below the horizon does not specify the object's true ground distance. The mapping of distance is still lawfully based on the angle of declination, but it no longer results in veridical perceived distance.

To illustrate, in Figure 2 we have diagramed the variables associated with the ADBH hypothesis as they pertain to objects on horizontal surfaces, as well as to objects on geographic slopes. Here the target object *T* (a grey cone) is located on a geographic slant (β) which produces an angle of declination below the horizon (α_{slope}) where

$$\alpha_{slope} = \tan^{-1} \frac{h - d \sin \beta}{d \cos \beta}$$

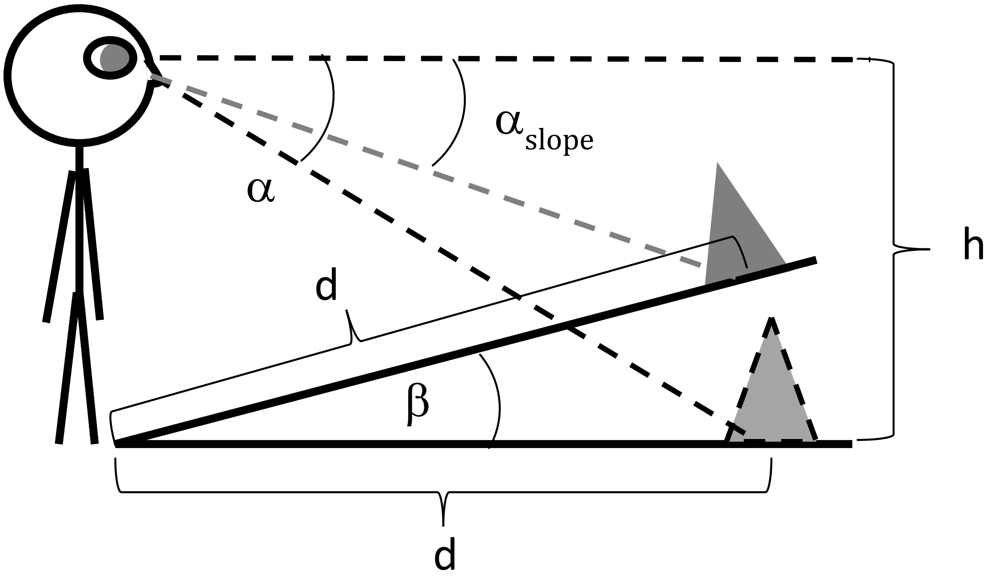

Figure 2. Generalization of the angular declination below horizon hypothesis for sloped surface.

According to the angular declination below the horizon hypothesis the physical angle of declination below the horizon (α_{slope}) would induce overestimates of perceived target distance (d_p). However, we have also diagrammed the projected angle of declination (α), or the angle of declination below the horizon for distance, which corresponds to target location *T'* which is essentially where *T* would be located if it were placed on the horizontal ground. It is important to note that when $\beta = 0^\circ$, that is when the ground surface is horizontal, α will be equal to α_{slope} because $T = T'$. Therefore, if an observer is capable of mentally placing the target (*T*) on the horizontal ground surface (a location corresponding to *T'*) and, therefore, be visually attentive to a projected angle of declination for ground distance (α), then distance (d) could accurately be determined because the perceived angle of declination below the horizon (α_{p}) would correspond to a perceived distance (d_p) that is equal to the actual ground distance (d) from observer to target.

In a recent investigation (Hajnal et al., 2014), we attempted to show that an invariant for distance perception exists in the form of an intrinsic ratio called a *π*-number (Warren, 1984; Warren & Whang, 1987). Our hypothesis was that participants would use the ratio formed by their eye height and the actual ground distance (*h/d*) to accurately perceive the distance to an object, irrespective of ground surface slope. This ratio would be specific to the projected angle of declination (α) for any given distance (d) regardless of the spatial configuration of the ground terrain such that:

$$\alpha = \tan^{-1}\frac{h}{d}.$$

Our investigation, which assessed distance perceptions to targets located on either a 0, 5, or 10 degree slope, showed that distance estimates were reasonably accurate, which is in contrast to what the ADBH hypothesis would have predicted. Furthermore, our results seemed to indicate that observers may, in fact, have been able to use α for perceiving distance because α proved invariant across slope conditions (see Hajnal et al., 2014, for a detailed explanation), meaning that it was a useful predictor of distance estimates irrespective of surface slope.

One of the constraints of the previous investigation was that it utilized an artificial ramp to produce the 5 and 10 degree slopes used in the experiment and during these two conditions a horizontal ground surface was visible in the background as part of the optic array at all times. Therefore, it is plausible that participants may have mentally placed the object on the horizontal background surface for reference purposes. If this is the case, then participants could still be relying on the object’s angle of declination below the horizon with respect to the horizontal surface, albeit a surrogate of sorts since they had to mentally relocate the object, to make their distance estimates. Therefore, the current investigation sought to test the findings of Hajnal et al.'s investigation with observations made at the bottom of a real hillside where a flat, horizontal surface was not visible within the optic array while making distance judgments. Since α is not directly visible when looking up a hill slope, we did not expect perception to be influenced by it. Instead, we hypothesized that observers would rely on α_{slope} as a source of information because that is the only angle that is visually and directly available. Such a result would offer more tightly controlled empirical evidence for the generalizability of the results of Hajnal et al. (2014).

Visual Perception and Effort

Thus far we have handled the perception of the visual world based solely upon the optical variables available to the attentive observer. However, this account of perception leaves one important piece of the perceptual puzzle out of the equation, namely, the observer. Each observer is to some extent different from every other observer. One may be taller than another, one may be fatigued, one may be in peak physical condition, and so on and so forth. It is possible that the state of the observer may impact his or her perception of the physical environment, particularly when the goal is to act upon that environment, which is usually the case in day to day perceptions. Therefore, it will benefit the reader to take into consideration the inclusion of some additional variables as potentially utilized by observers in making perceptual judgments.

A review of the relevant literature on slope perception may lead one to the findings of Stefanucci, Proffitt, Banton, and Epstein (2005) in which they determined that targets viewed on sloped surfaces, both uphill and downhill, are perceived as being further in distance than those viewed on flat, horizontal surfaces. In their investigation they sought to determine whether perceived effort (e.g., the perceived increase in metabolic effort required to traverse a given distance on a sloped surface as compared to the same distance on a horizontal surface) is an internal, organism specific variable that plays a role in the perception of distance. Their study is in many ways similar to both the Hajnal et al. (2014) study and the present investigation. For instance, all three studies assess distance estimates made on sloped surfaces and flat, horizontal surfaces and take into account optical variables that are believed to play a major role in visual perception. Above and beyond this, Stefanucci et al. (2005) also attempted to include perceived effort as a variable into their interpretation of the results. According to their effort hypothesis, distance estimates made to target objects placed onto a sloped surface should be exaggerated in comparison to distance judgments made to the same target distances on a horizontal ground surface because the amount of effort required to traverse a hill is greater than that required in walking across a horizontal surface. As support for this assumption it may be noted that Minetti, Ardigo, and Saibene (1993; 1994) have demonstrated that reducing stride frequency and walking speed are necessary responses in order to maintain a rate of metabolic output that is equal to the output used on horizontal surfaces. In an earlier investigation, Proffitt, Stefanucci, Banton, and Epstein (2003) found evidence that supported the effort hypothesis wherein they discovered that physical encumbrance (e.g., by wearing a heavy backpack) resulted in exaggerated distance estimates, most likely due to the perception of a necessary compensatory increase in metabolic output required to traverse the distance as compared to traversing the same distance unencumbered. There is, however, an area upon which the Stefanucci et al. (2005) investigation differs from Hajnal et al. (2014) and the present study. The Stefanucci et al. (2005) study included an additional factor as a component of what they believe to be the geometric information for the optical variables. The use of their chosen geometric variables produced a participant bias to perceive slopes as steeper than they are. For instance, they reported that what participants perceive to be 20˚ slants are actually 5˚ slants and slants perceived to be 30˚ are really only 10˚ (Proffitt, Bhalla, Gossweiler, & Midgett, 1995). Therefore, a target object located on a hill will be perceived optically as being physically closer to the observer than the same object at the same distance on a horizontal surface because the optical geometry employed here refers largely to the distance between an observer and the target as determined by the observer's direct line of sight. This serves to reduce the physical distance between an observer's eyes and the object and even more so due to the inherent human tendency to exaggerate slanted surfaces. They report that this produces a paradox wherein the perception of optical geometry specifies underestimations and the effort required to carry out the task specifies overestimates. While the present study and the Hajnal et al. (2014) study took into account some effort variables, we did not apply them to the optical geometry per se. Rather, we interpreted them as affecting perception directly instead of through optical shifting of the slope as seemed to be implied by Stefanucci et al. (2005). We employed the geometry referred to above in Ooi et al.'s (2001) ADBH which takes as the important optical information the horizon instead of the distance from observer to target as defined by line of sight. Importantly, Hajnal et al. (2014) and our present investigation assumed that perception of distance is determined by optical variables and effort based variables in a direct manner. What is common between the Stefanucci et al. study and the present investigation is the assertion that perceived effort produces an effect on the perception of distance, especially with regards to sloped surfaces.

The previous section has warranted that in addition to the optical variables previously mentioned, it is worthwhile to consider the possibility that anticipated effort might moderate the perception of distance, particularly across varying grades of slope. There exists evidence to suggest that traversing slopes necessitate the expenditure of energetic resources and may affect the way in which the visual system utilizes optical variables (Proffitt et al., 1995; Schnall, Zadra, & Proffitt, 2010). Proffitt (2006a) espoused an economy of action theory which takes the stance that visual perception is more than the pick-up of optical variables. Proffitt (2006a) asserted that there has to be an interaction between optical and ocular-motor information, motivation, physiological state, and emotions as variables for visual perception. According to Proffitt (2006a), when taking an organism's physiological state into consideration a fundamental law of life is that an organism that consumes energy must acquire more energy than it expends in order to replenish energy. Therefore, a successful system will become sensitive to the energetic costs associated with daily functions and will seek to conserve energy and spend only what is necessary for safe interactions with the environment. Proffitt (2006a) has noted that participant estimates of slope made by verbal and visual response result in overestimates of slope, mostly likely because they are explicit measures of slant. In a sense, it might be said that seeing an object which is difficult to get to as being further away prepares one to expend the extra energy necessary to safely accomplish the difficult task. This is demonstrated by the results of Proffitt et al. (2003) in which participants who were encumbered by a heavy backpack produced distance estimates that were greater than those of participants who were unencumbered by the backpacks.

How Could Effort be Measured and Operationalized?

The question of how to measure perceived effort requires the formation of an operational definition. Witt and Proffitt (2008) proposed that motor simulations may be employed to the task of relating a person’s abilities to the perception of the visual scene. They suggested that participants run a motor simulation of the task required so as to gauge the energetic or metabolic cost required of the task. In their own words, Witt and Proffitt (2008) said of motor simulations that, “Essentially, people imagine the performance of an intended action – either covertly or explicitly – and the outcome of this simulation influences perception” (p. 1479). In this way, an observer is free to decide which action to engage in based upon the expected outcome that is produced in the motor simulation. This is beneficial in that organisms can try out several possible actions so as to select the most beneficial and/or safe action without having to expend unnecessary energy in a potentially lengthy trial and error process. In light of the fact that people’s abilities and plans to engage in actions influence perception, any proposed mechanism must provide an assessment of the participant’s physical ability to carry out an action. Additionally, it must account for the participant’s anticipation of the outcome of the action as well as the expenditure of energy associated with completing the task, and it must also be future-oriented since organisms perceive the world for the purpose of acting upon those perceptions (Turvey, 1992). And lastly, it should be sensitive to the limitations inherent in the participant’s current physical state (whether those limitations are temporary or permanent). Witt and Proffitt (2008) suggested that the employment of motor simulations satisfies all of these requirements.

Traditionally, psychological studies have often assumed that temporal latencies reflect the amount of cognitive effort employed to complete the required task (Fawcett & Taylor, 2008; Jeannerod, 1995; Petit, Pegna, Mayer, & Hauert, 2003; Piolat, Olive, & Kellogg, 2004; Sarampalis, Kalluri, Edwards, & Hafter, 2009; Trawalter & Richeson, 2006; Wise & DeMars, 2006). In the present investigation the time spent observing the target object (t_{Obs}) was utilized as a measure of anticipated effort for traversing the distance observed. It is during this observation time that we propose participants will generate their motor simulation for traversing the observed distance. It is during this observation time that participants, whether explicitly or implicitly, will take into account the optical variables provided by the ambient optic array in addition to their own perceived ability to replicate the distance viewed. Thus, participants are likely to take into account the distance to the target in addition to the effort that will be required to traverse that distance. If perceived effort is a component of distance perception, sloped surfaces should require the expenditure of more energy to traverse a given distance as the energy required to traverse the same distance on a horizontal surface. Therefore, it is our belief that increases in observation time will result in increases in perceived distance (because encoding the information for greater distances requires more cognitive effort). However, it may also be the case that longer observation times reflect deeper and richer encoding of the optical variables present in the visual scene. If this is the case, it should be that observation time will interact with the physical angle of declination below the horizon

(α_{Slope}) as an object rest in the visual scene, as it is the optical basis of information specifying distance.

Likewise, response time (t_{Resp}) may also exert an effect upon perception in that longer response times result in the decay of encoded information. Thus, the longer it takes for a participant to make his or her response, the weaker the visual trace becomes (e.g., Binsted, Rolheiser, & Chua, 2006; Rolheiser, Binstead, & Brownell, 2006). Therefore, greater response times should result in smaller α_p and, thus, greater perceived distance.[1]

In addition to the temporal variables of observation and response time, it is also possible for us to calculate two effort variables: actual speed (s_{Actual}) and simulated speed (s_{Simu}). Speed-based variables may capture the alleged mechanisms that describe the management of energetic resources over time and space for a given perceptual task. Simulated speed, as determined by dividing the observed distance by the response time (d/t_{Resp}), provides a measure of intended effort expenditure. Greater simulated speed should result in stronger effects of the optical variables on perceived distance through repeated rehearsal of visual traces. This could be achieved by trying to encode actual distance-to-target to the best of one's ability by budgeting as little of t_{Resp} as possible. Storing larger distances and budgeting shorter t_{Resp} may result in large intended speeds, and this could be a signature of an efficient representational system that budgets its resources mindful of future energetic needs. Efficient budgeting of anticipated effort may

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[1] The distance estimates produced by participants during the response phase (d_{Resp}) can be used to calculate the perceived angular declination (α_p) which is a linear function of the actual angle of declination observed (α_{Slope}). This paper takes the stance that α_p serves as a source of perceptual information used by participants during the response phase to assist in determining when the proper distance has been replicated and thus when to terminate the response.

strengthen the reliance on optical variables for perceiving α_p. Actual speed, determined by dividing perceived distance by response time (d_{Resp}/t_{Resp}), should produce the opposite effect such that greater actual speed decreases the effect of optical variables on perceived distance. The logic behind this assumption is that increasing the level of energy expenditure comes at the cost of allocating attention away from visual traces to be employed in the task of locomotion (blind-walking, see Hajnal et al., 2014) or other motor responses (such as rope-pulling, see Chapter II of the current experiment). It has been observed in past studies that attention which is usually employed in the task of storing and responding to perceptual information is divided between perception and action such that increased demands of action result in decreases in attentional resources for perception (e.g., Shanks, Rowland, & Ranger, 2005).

The Hajnal et al. (2014) investigation was our preliminary look into the interaction between optical and effort variables on distance perception across varying grades of slope. In that investigation participants were required to make distance estimates to targets that were placed onto either a horizontal ground surface, a surface with a 5˚ slope, or a surface with a 10˚ slope. We measured the amount of time it took observers to gaze at the test stimuli (an orange cone placed at one of five distances). This was the observation phase of the experiment. During the response phase, in which participants engaged in a blind-walking task to reproduce the distance observed in the observation phase, we measured the distance traversed by participants as well as the time it took for them to complete the response. These measurements were used to calculate our effort variables as mentioned above. Our predictions for that study were that with regards to the observed distance, observation time and anticipated response speed would accentuate the effects of encoded optical variables. Additionally, we expected that relative to the distance traversed by participants, response time and response speed would reduce the effects of encoded optical variables. All of these predictions were substantiated save for those regarding observation time. This finding was surprising in that there should exist some benefit inherent to longer observation times such that longer durations of study serve to strengthen the formation of memory traces. This lack of confirmation raises questions about whether or not representational encoding of the optical variables occurs to service visual traces used in the response phase.

Statement of Hypotheses

In the present investigation we sought to investigate the effects of optical variables in addition to each participant's effortful contributions to the pickup of visual information on a trial-by-trial basis, as these should moderate the effects of the optical variables (Palatinus, Dixon, & Kelty-Stephen, 2013; Stephen & Hajnal, 2011). Therefore, Hypothesis 1 predicts that there will exist a positive effect of α_{Slope} on α_{p}. Hypothesis 2a predicts a negative effect of t_{Obs} on α_{p}. Hypotheses 2b through 5 predict that the effects of our latency and effort measures will moderate the effects of the optical variables such that t_{Obs} will accentuate the effects of optical variables (such as α_{Slope}) on α_{p} (Hypothesis 2b). Likewise, s_{Simu} will increase the effects of the optical variables on α_{p} (Hypothesis 4). Conversely, t_{Resp} and s_{Actual} will reduce the effect of the optical variables (Hypotheses 3 and 5, respectively) due to decay of the visual trace of the simulated action plan, and perceptuomotor interference between attention to the visual trace and attention to the response activity, respectively. Since we planned to employ a relatively novel response activity of blind rope-pulling to estimate distance, we thought it best to train observers with this task. Therefore, our final Hypothesis 6 stated that training with feedback will strengthen reliance on optics and make the contribution of effort-based variables superfluous.

CHAPTER II

METHOD

Participants

A total of 90 participants were recruited through the University of Southern Mississippi’s experiment participation website and received course credit for their participation in the study. All participants had normal or corrected-to-normal vision. All procedures were approved by the Institutional Review Board of The University of Southern Mississippi. Participants were randomly assigned to 6 groups of 15 individuals across two experiments.

Apparatus

The present investigation was conducted outdoors on real hillsides as well as on an open horizontal field under well-lit conditions. The zero degree condition was conducted on The University of Southern Mississippi’s Centennial Green, a field of grass which is roughly uniform in texture and horizontal and flat in orientation (see Figure 3). For the 5 and 10 degree slopes we utilized a series of hills located next to the intramural soccer fields behind The University of Southern Mississippi’s Reed Green Coliseum (see Figures 4 and 5). The two hills were both fairly uniform in texture; that is, they are grass-covered, and both were roughly consistent in angle. That is to say that one of the hills roughly approximated a 5 degree slope and the other a 10 degree slope. Permission to use the areas mentioned was obtained from the appropriate authorities prior to data collection.

Figure 3. The 0 degree slope condition with participant gazing at target cone. Target cone is placed on the horizontal surface of The University of Southern Mississippi's Centennial Green.

Figure 4. The 5 degree slope condition with participant gazing at target cone. Target cone is placed on a hill of roughly 5 degrees near The University of Southern Mississippi's Intramural Soccer Fields.

Figure 5. The 10 degree slope condition with participant gazing at target cone. Target cone is placed on a hill of roughly 10 degrees near The University of Southern Mississippi's Intramural Soccer Fields.

Procedure

Two experiments were conducted to test distance perception on a sloped surface. Both experiments are exactly the same in every aspect except for the training procedure used to calibrate participants in the response measure to be used. Both experiments utilized a blind rope-pulling response measure to assess participant perceptions of distance; however, in the first experiment participants did not receive any training on the response measure, whereas participants in the second experiment did. Blind rope-pulling shows promise as a response measure for distance perception, somewhat akin to blind-walking which has been utilized quite extensively in the literature (for examples see Loomis et al., 1992; Loomis et al,. 1996; Thomson, 1983). We chose this particular response measure for two reasons. The first is that when utilizing the procedure devised by Philbeck, Woods, Kontra, and Zdenkova (2010), blind rope-pulling includes a cyclic motion of hand-over-hand rope-pulling similar in nature to that used by the legs when blind-walking. And secondly, we chose this procedure because we felt that it was too dangerous to ask participants to walk blindfolded across sloped surfaces for fear that they may fall and injure themselves. In addition, we did not want to use a pantomime blind-walking procedure because pantomime blind-walking has been criticized in the literature as less representative of true distance perception due to its indirect nature as compared to blind-walking to the actual target location (Li et al., 2012). [2]

Because there are only two studies (Philbeck et al., 2010; Yamamoto & Hirsch, 2012) which have utilized this particular version of the blind rope-pulling procedure, we felt it necessary to explore the validity of this particular response measure. Therefore, the zero degree condition of the present experiments attempted to replicate the findings of Philbeck et al.'s (2010) Experiment 4.

Experiment 1

In Experiment 1 (No Training), blindfolded participants were placed in the middle of the Centennial Green (for the zero degree condition) or at the bottom of either the 5 or 10 degree hills located next to The University of Southern Mississippi's Reed Green Coliseum. Participants were assigned to one condition only. Therefore, data collected in the zero degree, 5 degree and 10 degree conditions were independent with respect to the participants used in the other conditions. At the start of each trial the participants were given a 5-digit number to memorize. This number was intended to serve as a cognitive distraction to prevent participants from counting how many pulls are necessary to

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[2] When blind-walking, participants attempt to walk to the actual location of the target object, thus reproducing both distance and spatial location. Pantomime blind walking is an attempt to reproduce the target distance in any direction, but does not involve walking to the actual target location.

reproduce the distance. Participants were then required to recall this number at the end of each trial. We did not retain information regarding the accuracy of the recall task. Next, participants were told to remove the blindfold and to view the target object (one of three different sized orange cones: a large cone with a square base 22.86 cm on each side and a height of 30.48 cm, a medium orange cone with a square base 13.34 cm on each side and a height of 24.13 cm, a small sized cone with a round base 17.78 cm in diameter and a height of 5.40 cm) that had been placed on the ground surface at a set distance. This constituted the observation phase of each trial. The distances utilized in this experiment (and in Experiment 2) were set at 1.83, 2.44, 3.05, 3.66, and 4.27 m (the same distances used in Hajnal et al., 2014). The presentation of each distance was repeated three times (three blocks of the five distances) during the experiment with the order of presentation occurring randomly within a repetition such that each consecutive 5-trial block contained a random presentation of the five different distances. Each participant underwent 15 separate trials in total.

Once a participant had visually inspected the distance from their feet to the target object during the observation phase he or she then donned the blindfold. This began the response phase of each trial wherein the participant was given a length of measuring tape (a spool of flexible measuring tape 300 feet in total length). When told to begin, the participant would proceed to pull a length of tape through their hands until they pulled out a length of tape they felt approximated the distance viewed in the observation phase. Then they were required hold the tape between their thumb and forefinger, careful to mark the exact spot they felt approximated the distance viewed, and a researcher would then record the distance reproduced by the participant as indicated by the amount of tape held by the participant. At this point the participant was asked to recall the 5-digit number they were given to memorize at the beginning of the trial. Afterwards, another distance was measured off and the process began again at the next observation phase.

In addition to data collected on participant distance estimations, we also collected data on the amount of time it took participants to make their determinations. Therefore, we recorded the amount of time each participant took to observe the actual distance (observation time measurement) and the time it took them to reproduce the distances (response time measurement). These were recorded for all experimental trials in all conditions.

After the participant had completed his/her participation in the experiment, a measurement of his/her eye-height was obtained along with various other types of demographic data (e.g., age and gender).

Experiment 2

In Experiment 2 (Training) participants underwent the exact same procedure as in Experiment 1, including observation and response time measurements, except that in Experiment 2 participants received training in the blind rope-pulling task before engaging in the actual experiment. Training was divided into two blocks. In both training blocks a paperclip was attached to the tape used for the response measure at the specific distance viewed for that particular training trial. This served to inform the participant when they should cease pulling the tape in order to accurately reproduce the distance viewed. For the first training block, participants were allowed to see the amount of tape that was being pulled through their hands as they pulled it. However, the second block of training trials was conducted with the eyes covered so that the only feedback the participant received was from the feel of the paperclip, which served as a stopper of sorts. Both blocks of training trials used the same five distances (1.52, 2.13, 2.74, 3.35, and 3.96 m); however, these distances were randomized in each block. After both blocks of training trials were complete, the experiment proceeded in the same fashion as Experiment 1 except that participants were given one recalibration trial between the 7th and 8th experimental trials. This recalibration trial was conducted in the same manner as the eyes open training trials and always used the distance of 3.96 m. After the recalibration trial was completed, the experiment continued on as in Experiment 1.

The 5 and 10 degree conditions both took place in the same general area on a grassy space located behind The University of Southern Mississippi's Reed Green Coliseum. A participant was assigned to only one of the conditions (either 5 or 10 degree slopes). For the 10 degree conditions, participants made their distance judgments while facing north at the base of a hill that was roughly 10 degrees in slope (Figure 5). Participants in the 5 degree condition were required to face west at the base of a hill that was roughly 5 degrees in slope (Figure 4). The procedures for these two conditions, across both experiments, were exactly the same as the ones used in the zero degree condition, the only difference being that for these two conditions participants were making distance estimates to objects placed on either a 5 or 10 degree slope. See Figure 3, 4, and 5 for details of the experimental setup and the stimulus surface.

Experimental Design

The data from each experiment was analyzed with a 3×2×5 mixed analysis of variance (ANOVA) using Slope Angle (β equals 0, 5, and 10 degrees) and Training as between-subjects variables, and Distance (1.83, 2.44, 3.05, 3.66, and 4.27 m) as a within-subjects variable, with perceived distance (d_{Resp}) as the dependent measure. The three repetitions for each distance were averaged for each person, contributing to the group means.

To provide a more refined understanding of space perception, and to investigate potential candidates for specifying information, we computed several relevant variables on all trials for each participant: the actual angle of declination (α_{Slope}), perceived angle of declination (α_{p}), and α, the angle of declination corresponding to the projected location (T') of the target object if it were resting on the horizontal ground at the same distance (see Figure 2). A linear regression of perceived angle of declination (α_{p}) against the physical angle of declination below the horizon (α_{Slope}) was calculated for each participant with an associated regression slope and intercept. Our hypothesis was that if a specifying variable is used across all three slope angles, this would be revealed by virtually identical scaling of perception to information as reflected by comparable regression slope values. In cases where the invariant information scales to perception with a regression slope near 1, it would indicate not only reliance on specifying information, but also optimal calibration.

To provide insight into the temporal aspects of perception, such as the contribution of observation time and response time to the prediction of perceived distance, we employed multi-level modeling (Singer & Willett, 2003). This method may reveal how trial-by-trial changes in perception are predictable both by temporal and spatial aspects of the perceptual task. All hypotheses regarding α_{p} were tested using multi-level modeling (MLM; Singer & Willett, 2003). MLM is a multiple linear regression technique, similar in form to ordinary least-squares (OLS) regression techniques such as repeated-measures analysis of variance (RM-ANOVA), and like OLS regression, MLM estimates coefficients for each predictor whose magnitude and sign indicates the size and direction of that predictor's effect on the outcome measure. However, an important advantage to MLM compared to RM-ANOVA is that it uses a maximum-likelihood (ML) estimation better suited to estimating effects of time-varying predictors and fitting random effects to account for individual differences across subjects. Another difference is that, whereas improvement of model fit under OLS estimation is expressed in terms of a change in R-squared, ML estimation evaluates improvements in model fit in terms of a "-2 LL" deviance statistic calculated as -2 times log likelihood (LL). The size of -2 LL is tested as a chi-square statistic with as many degrees of freedom as there are new predictors added. MLM has proven to be well-suited to modeling effects on perceptual judgments (Blau, Stephen, Carello, & Turvey, 2009; Palatinus et al., 2013; Stephen & Arzamarski, 2009; Stephen, Arzamarski, & Michaels, 2010; Stephen & Hajnal, 2011). A truly perceptual level of responding should reveal a great contribution of the response process and minimal influence of the preparatory (observation) stage of the process, thus potentially obviating the need for explanations involving higher cognition, preplanning, second guessing, and other possible detractors from a true assessment of direct perception.

CHAPTER III

RESULTS

We conducted a 3 (Slope Angle β: 0, 5, 10°) × 2 (Training: yes, no) × 5 (Distance) repeated-measures ANOVA on perceived distance d_{Resp} as the dependent measure using Slope Angle and Training as between-subjects independent variables. There was a significant main effect of Training, $F(1, 84)=34.43$, $p<.001$, suggesting that perceived distance became more accurate after receiving training with rope pulling. This main effect was further qualified by a significant Distance × Training interaction, $F(4, 336)=16.3$, $p<.001$, suggesting that longer distances benefited from training to a larger extent than shorter distances. The interaction revealed that longer distances were increasingly more underestimated than shorter distances in the absence of training. No main effects or interactions involving Slope Angle were significant indicating that Slope Angle did not have a direct influence on distance perception. It is worth noting that the absence of significant main effects involving Slope Angle is in contrast to the results obtained by Hajnal et al. (2014) where a significant Slope Angle × Distance interaction was found. The results of the present analyses involving d_{Resp} as the dependent measure are depicted in Figure 6.

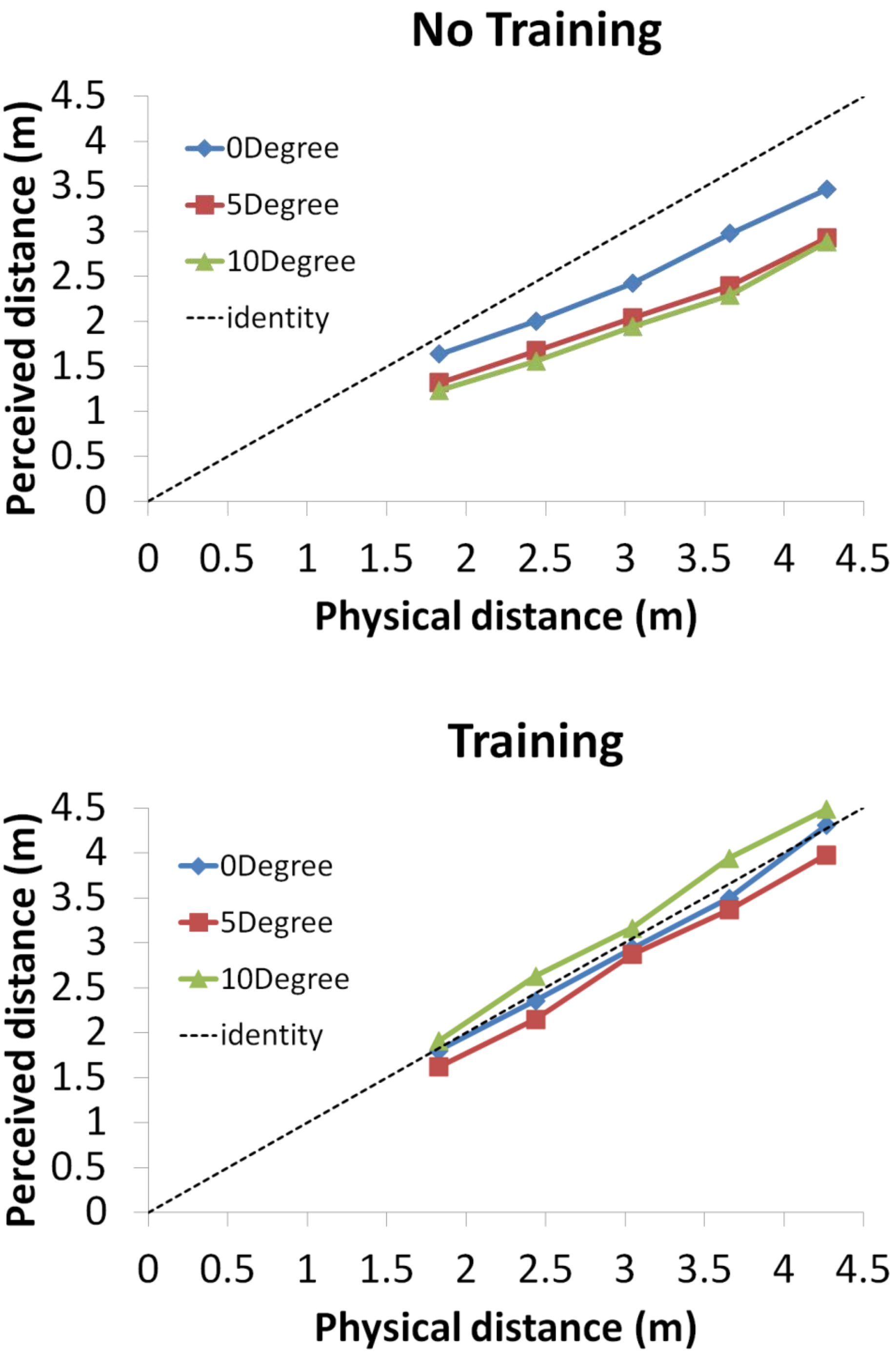


Figure 6. Perceived distance (d_{Resp}) as a function of physical distance (d) and slope angle (β: 0, 5, and 10 degree hills). The top panel shows the group that received no training on rope pulling (Experiment 1), whereas the bottom panel indicates the results of the group that received training on rope pulling (Experiment 2).

Next, we converted all distances into their respective angular declinations such that physical distance (d) corresponded to physical angular declination (α_{Slope}), and perceived distance (d_{Resp}) corresponded to perceived angular declination (α_{p}). The results are shown in scatterplots in Figure 7. As noted earlier, angular declination was used in all subsequent analyses, as it is a variable that is scaled to each individual observer's eye height, and is hypothesized to serve as the informational basis for target location. As is apparent from Figure 7, calibration was excellent with regression slopes ranging from 0.91 to 1.12. Training caused a decrease in intercepts and an increase in variance explained (r^2) in all groups.

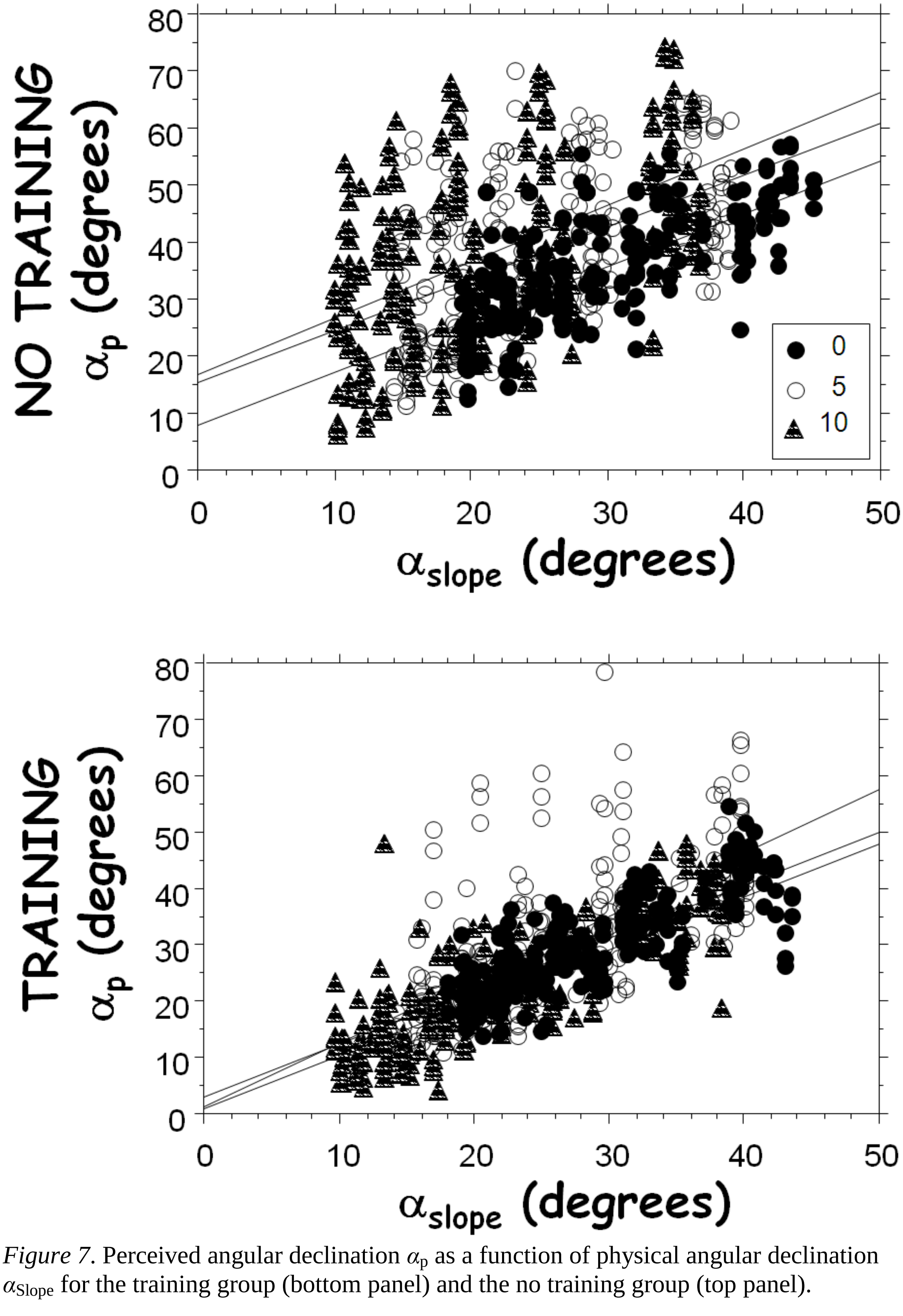


Figure 7. Perceived angular declination α_p as a function of physical angular declination α_{Slope} for the training group (bottom panel) and the no training group (top panel).

The next set of analyses employed multi-level modeling as described in Chapter II. Model 1 tested the effects of optical variables on visual information for visually guided distance perception (referring to Hypothesis 1). Specifically, the model looked at the effects of α_{Slope}, α, and $\alpha_{\text{Slope}} \times \alpha$. The model returned significant positive main effects for both α_{Slope} and α ($B = 0.8536$, SE = 0.1619, $p < .0001$; $B = 0.8850$, SE = 0.1978, $p < .0001$, respectively). Thus, perceived angle of declination α_{p} increased with the actual angular declination with respect to the sloped terrain α_{Slope}, but also with increases of angular declination to the horizontal ground α (even though the horizontal ground was not visible to participants in the 5 and 10 degree slope conditions). In addition, the model returned a significant negative $\alpha_{\text{Slope}} \times \alpha$ interaction ($B = -0.0121$, SE = 0.0023, $p < .0001$), suggesting that the interaction served to weaken the effects of both optical variables. The results of Model 1 are presented in Table 1.

Table 1

Table of All Individual Predictors in Model 1

Predictor	*B*	SE	*p*
Intercept	-5.598	2.329	.02
α_{Slope}	.8536	.1619	< .0001
α	.8850	.1978	< .0001
$\alpha_{\text{Slope}} \times \alpha$	-.0121	.0023	< .0001

Model 2 sought to test for moderating effects of effort and training on the optical variables utilized as visual information for distance perception (referring to Hypotheses 2-6). Adding 44 new predictors led to significantly large changes in -2 LL Deviance, $\chi^2(44) = 2{,}105.36$, $p < .0001$, which indicates a significant improvement in model fit.

Therefore, the incorporation of effort-related predictors into the model significantly improved the prediction of perceived angular declination below the horizon and thus, perceived distance. The results of the model comparisons are presented in Table 2.

Table 2

Predictors Composing Model 1 and Model 2

Model	Highest order interactions	Number of added predictors	χ^2	p
1	$\alpha \times \alpha_{\text{Slope}}$			
2	$Training \times t_{\text{Obs}} \times \alpha \times \alpha_{\text{Slope}}$ + $Training \times t_{\text{Resp}} \times \alpha \times \alpha_{\text{Slope}}$ + $Training \times d \times \alpha \times \alpha_{\text{Slope}}$ + $Training \times s_{\text{Simu}} \times \alpha \times \alpha_{\text{Slope}}$ + $Training \times s_{\text{Actual}} \times \alpha \times \alpha_{\text{Slope}}$ + $Training \times \alpha \times \alpha_{\text{Slope}}$	44	2105.36	< .0001

Next, we looked at the specific effects and interactions included in Model 2. As illustrated in Table 3, the main effect of α observed in Model 1 did not prove significant in Model 2 (B = 1.923, SE = 1.464, p = .19). However, the main effect of α_{Slope} remained significant (B = -3.583, SE = 1.226, p < .004), which indicates that perceived angular declination was influenced by the visual information available to the observer. Qualifying this main effect, there was a significant $Training \times \alpha_{\text{Slope}}$ interaction (B = 6.457, SE = 1.786, p < .0003), which indicated that training facilitates the observer's reliance on the available optical information most relevant for perception. Taken together, these findings confirmed the assumptions set forth in Hypotheses 1 and 6. Namely, observers would rely on the visual information made available (α_{Slope}) and that training would promote reliance upon this information.

Table 3

Coefficients from Model 2.

Predictor	*B*	SE	*p*
Intercept	69.563	32.543	.03
Effects of optical variables on α_{p}			
α_{Slope}	-3.583	1.226	< .004
α	1.923	1.464	.19
$\alpha_{\text{Slope}}\times\alpha$	.0451	.0340	.19
$\mathit{Training}\times\alpha_{\text{Slope}}$	6.457	1.786	< .0003
Effects of observation time on use of optical variables for α_{p}			
t_{Obs}	-1.416	2.451	.56
$t_{\text{Obs}}\times\alpha_{\text{Slope}}$	-.0064	.1173	.96
$t_{\text{Obs}}\times\alpha$	.1186	.1351	.38
$t_{\text{Obs}}\times\alpha_{\text{Slope}}\times\alpha$	-.0019	.0029	.51
Controlling for effect of observed distance on use of optical variables			
d	4.781	4.939	.33
$d\times\alpha_{\text{Slope}}$	-.2519	.1724	.14
$d\times\alpha$	.0471	.2647	.86
$d\times\alpha_{\text{Slope}}\times\alpha$	-.0053	.0065	.41
Effects of response time on use of optical variables for α_{p}			
t_{Resp}	-28.9698	14.2784	< .043
$t_{\text{Resp}}\times\alpha_{\text{Slope}}$	1.673	.5297	< .002
$t_{\text{Resp}}\times\alpha$	-.0605	.7051	.93
$t_{\text{Resp}}\times\alpha_{\text{Slope}}\times\alpha$	-.0240	.0160	.13
$\mathit{Training}\times t_{\text{Resp}}\times\alpha_{\text{Slope}}$	-2.397	.825	< .004
Effects of simulated speed on use of optical variables for α_{p}			
s_{Simu}	-47.9775	36.3977	.19
$s_{\text{Simu}}\times\alpha_{\text{Slope}}$	3.436	1.3948	< .014
$s_{\text{Simu}}\times\alpha$	2.0711	1.7799	.24
$s_{\text{Simu}}\times\alpha_{\text{Slope}}\times\alpha$	-.0743	.0403	.07
$\mathit{Training}\times s_{\text{Simu}}\times\alpha_{\text{Slope}}$	-5.252	2.170	< .016
Effects of actual speed on use of optical variables for α_{p}			
s_{Actual}	-0.1877	14.0493	.99
$s_{\text{Actual}}\times\alpha_{\text{Slope}}$	3.603	.6989	< .0001
$s_{\text{Actual}}\times\alpha$	-7.746	.7860	< .0001
$s_{\text{Actual}}\times\alpha_{\text{Slope}}\times\alpha$	.0604	.0177	< .0006
$\mathit{Training}\times s_{\text{Actual}}\times\alpha_{\text{Slope}}$	-4.147	.958	< .001
$\mathit{Training}\times s_{\text{Actual}}\times\alpha$	2.616	1.120	< .020

All interactions with effort based variables were included; however, only significant interactions with Training are presented to save space.

Hypothesis 2 pertained to any effects of t_{Obs} on perceived angle of declination and was composed of two parts. The first part predicted a negative effect of t_{Obs} on perceived angle of declination, whereas the second part predicted that t_{Obs} would have a positive effect on the use of optical variables, particularly α_{Slope}. However, there were no significant effects of t_{Obs} on any of the included variables. This finding would seem to cast doubt upon the usefulness of motor simulation during stimulus observation. In addition, actual physical distance (d) did not contribute to the use of optical variables and did not influence perception in meaningful ways, as indicated by the absence of statistically significant effects of optics and physical distance.

Hypothesis 3 posited that greater t_{Resp} would reduce the effect of optical variables on perceived angular declination because the information would decay with time. While there was a significant main effect of t_{Resp} ($B = -28.9698$, SE = 14.2784, $p < .043$) and a significant interaction of $t_{\mathrm{Resp}} \times \alpha_{\mathrm{Slope}}$ ($B = 1.673$, SE = .5297, $p < .002$), the most meaningful significant finding was a negative interaction of $Training \times t_{\mathrm{Resp}} \times \alpha_{\mathrm{Slope}}$ ($B = -2.397$, SE = .825, $p < .004$). These findings indicated that training may have neutralized any potential effect of memory decay on the visual trace, which is consistent with both Hypothesis 3 as well as Hypothesis 6. Essentially, the effects of memory decay weakened the influence of optics only in the context of the observer being trained, perhaps because training made up for memory decay by “artificially” propping up perception via feedback.

Hypothesis 4 stated that s_{Simu} would increase the effects of the optical variables on perceived angular declination. The data showed a positive interaction of $s_{\mathrm{Simu}} \times \alpha_{\mathrm{Slope}}$ ($B = 3.436$, SE = 1.3948, $p < .014$), which would seem to corroborate Hypothesis 4.

However, there was also a negative interaction of $Training \times s_{\text{Simu}} \times \alpha_{\text{Slope}}$ (B = -5.252, SE = 2.170, $p < .016$), which indicated that training neutralized any potential benefit from rehearsing and engaging representations during observation and rendered the planned management of energetic resources irrelevant, which is consistent with Hypothesis 6. In short, training weakened the alleged enhancement of optics by planned effort, perhaps making its contribution unnecessary.

Hypothesis 5 predicted that s_{Actual} would reduce the effect of the optical variables due to perceptuomotor interference from the response task. There was no observed main effect of s_{Actual} on perceived angular declination; however, there were several significant interactions: $s_{\text{Actual}} \times \alpha_{\text{Slope}}$ (B = 3.603, SE = .6989, $p < .0001$), $s_{\text{Actual}} \times \alpha$ (B = -7.746, SE = .7860, $p < .0001$), $s_{\text{Actual}} \times \alpha_{\text{Slope}} \times \alpha$ (B = .0604, SE = .0177, $p <$ .0006), $Training \times s_{\text{Actual}} \times \alpha_{\text{Slope}}$ (B = -4.147, SE = .958, $p < .001$), and $Training \times s_{\text{Actual}} \times \alpha$ (B = 2.616, SE = 1.120, $p < .020$). Of these interactions, the most comprehensive and meaningful is the highest order, negative interaction of $Training \times s_{\text{Actual}} \times \alpha_{\text{Slope}}$, which indicated that training annulled the effect of interference between motor activity and attention to internal representations of available optics. This suggested that training perhaps moves the perceptual system towards diminishing the reliance on relevant optics and is consistent with Hypothesis 5 and Hypothesis 6. Interestingly, the positive interaction of $Training \times s_{\text{Actual}} \times \alpha$ indicated that during training increased effort was spent on amplifying the role of non-visible optics. As we have seen in the previous interaction, actual effort diminished influence on relevant optics. Training with feedback made perception more accurate and, thus, consistent with non-visible optics (α). This work was done by actual effort, while divesting attention from relevant optics (α_{Slope}) and was consistent with Hypothesis 6.

CHAPTER IV

DISCUSSION

The present research sought to elaborate on the Hajnal et al. (2014) investigation of the interaction between optical and effort variables on distance perception across varying grades of sloped surfaces. Both investigations required participants to make distance estimates to targets that were placed onto either a horizontal ground surface, a surface with a slope of 5˚, or a surface with a 10˚ slope. The present investigation used real hillsides where a horizontal surface was not visible in the slope conditions, whereas the former utilized a ramp to produce the sloped surfaces, making the horizontal background visible. In both experiments we measured observation time and response time in addition to distance perceived to calculate effort variables. In the present investigation we opted for a blind rope-pulling response as opposed to the blind-walking response used in Hajnal et al. (2014). The change of response measure was deemed necessary because we felt that it was too dangerous to ask participants to walk blindfolded across sloped surfaces as it may pose a fall risk to the participants. There were several features that were similar to both rope-pulling and blind-walking. When utilizing the procedure devised by Philbeck et al. (2010), blind rope-pulling requires a cyclic hand-over-hand motion akin to that used by the legs when blind-walking. Another difference between the present investigation and the Hajnal et al. (2014) study was that due to the inclusion of our new response measure it was necessary to include the additional variable of training, as it was necessary that participants be trained in the rope pulling technique in order to produce reliable and accurate responses.

Perceived distance became more accurate after training with rope-pulling, and perception of targets at longer distances benefited from training to a greater degree than shorter distances. Also of note was the finding that slope angle did not have a direct influence on distance perception, which conflicts with the results obtained by Hajnal et al. (2014) where a significant interaction between slope angle and distance was found. The present work investigated six hypotheses aimed at determining the effects of optical variables, effort-related variables, and training on distance perception to targets on sloped surfaces as measured with a blind rope-pulling task. Each of these hypotheses utilized α_{p}, the perceived angular declination, as the dependent variable for analysis. As part of multilevel modeling analysis Model 1, which pertained to Hypothesis 1, tested the effects of purely optical variables on visual information for visually guided distance perception and looked specifically at the effects of α_{Slope}, α, and $\alpha_{\mathrm{Slope}}\times\alpha$. It was predicted that α_{p} would be related to α_{Slope} and would also be impacted by a negative interaction of α_{Slope} and α. The model returned significant positive main effects for both α_{Slope} and α in addition to a significant negative $\alpha_{\mathrm{Slope}}\times\alpha$ interaction. Thus, as predicted, perceived angle of declination α_{p} increased with the angular declination of the physical terrain α_{Slope}, but also with increases of angular declination to the horizontal ground α (even though the horizontal ground was not visible to participants in the 5 and 10 degree slope conditions). The negative interaction pointed to opposing and differential effects of both optical variables on distance perception.

With the exception of Hypothesis 6, which stated that training should strengthen reliance on optics and weaken the contribution of effort-based variables, the remainder of the hypotheses investigated the effects of effort-related variables on distance perception.

Hypothesis 2 sought to uncover any effects of t_{Obs} on perceived angle of declination and was composed of two parts. Hypothesis 2a predicted a negative effect of t_{Obs} on α_{p}, whereas Hypothesis 2b predicted that t_{Obs} would have a positive effect on the use of optical variables, particularly α_{Slope}. However, the present work found no significant effects of t_{Obs} whatsoever, which casts some doubt upon the presence and usefulness of motor simulation during observation.

Hypothesis 3 stated that t_{Resp} would reduce the effect of the optical variables on perceived angular declination because the information would decay with time. While it was observed that there existed a main effect of t_{Resp} and a positive $t_{\text{Resp}}\times\alpha_{\text{Slope}}$ interaction, the most meaningful finding was the negative interaction between $\mathit{Training}\times t_{\text{Resp}}\times\alpha_{\text{Slope}}$, which indicated that training may in fact neutralize memory decay of the visual trace. In other words, the effects of memory decay seem to weaken the influence of optics but only in the context of the observer being trained. Perhaps training compensated for any potential memory decay by “artificially” propping up perception via feedback. These findings are consistent with both Hypothesis 3 and Hypothesis 6.

Hypothesis 4 was our assertion that s_{Simu} would increase the effects of the optical variables on perceived angular declination. At first it seemed to be supported by the positive $s_{\text{Simu}}\times\alpha_{\text{Slope}}$ interaction; however, there was also a negative interaction of $\mathit{Training}\times s_{\text{Simu}}\times\alpha_{\text{Slope}}$. This would seem to indicate that training neutralized any potential benefit on the usage of optical information from rehearsing and engaging representations during observation. If this is the case it would render the planned management of energetic resources irrelevant for visual perception. That training appears to have weakened the contribution of planned effort, perhaps making its contribution unnecessary, is consistent with Hypothesis 6.

Hypothesis 5 predicted that s_{Actual} would reduce the effect of the optical variables due to perceptuomotor interference from the response task. There was no observed main effect of s_{Actual} on perceived angular declination; however, there were several significant interactions. Of these interactions, the most noteworthy are those that involved training as a component ($Training \times s_{\mathrm{Actual}} \times \alpha_{\mathrm{Slope}}$ and $Training \times s_{\mathrm{Actual}} \times \alpha$). The negative $Training \times s_{\mathrm{Actual}} \times \alpha_{\mathrm{Slope}}$ interaction can be broken down into two simpler interactions: $s_{\mathrm{Actual}} \times \alpha_{\mathrm{Slope}}$, analyzed separately, with or without training. In the absence of training there was a significant positive interaction between visible optics and actual effort. During training this interaction fizzled out. The diminishing positive interaction brought to life the significant negative $Training \times s_{\mathrm{Actual}} \times \alpha_{\mathrm{Slope}}$ interaction. This finding is consistent with Hypothesis 5 because it indicated the increasingly weakening role of actual effort in facilitating reliance on visible optics. Hypothesis 6 predicted that reliance on optics would become stronger with training. The current interaction was in partial agreement with this hypothesis. Although reliance on relevant visible optics (α_{Slope}) was suppressed by training, the significant positive interaction of training with nonvisible optics (α) tells us that not all optical variables were suppressed by training. The positive $Training \times s_{\mathrm{Actual}} \times \alpha$ interaction would seem to indicate that increased effort was spent on amplifying non-visible optics during training. Therefore, the data suggested that actual effort diminished influence on relevant optics. At the same time training with feedback made perception more accurate, thus consistent with non-visible optics (α). This work was done by actual effort, while diverting attention from relevant optics (α_{Slope}) and is consistent with part of Hypothesis 6. Specifically, in the context of these two significant interactions with Training, it is apparent that the visual system shifted from reliance on visually available optical information (α_{Slope}) to reliance on visually unavailable optical information (α). It may be the case that training with feedback breaks the natural link between information that specifies target location (α_{Slope}) and perception (α_{p}). Even though α_{p} (as reliant on information) resulted in consistently inaccurate responses (according to Figure 6, mostly underestimating distance), it was nevertheless lawfully based on specifying information. This result is consistent with the theory of direct perception (Gibson, 1979): perception uniquely maps onto specifying information without necessarily being accurate. Feedback in the present task facilitated accuracy in an artificial, non-informationally based manner.

Our current findings are similar to the findings of Hajnal et al. (2014), particularly in that they both failed to substantiate the claims of Hypothesis 2 regarding the effects of t_{Obs} on perceived angle of declination. Although it is reasonable to believe that time spent encoding a variable is related to the richness of the encoded visual trace, it is strikingly remarkable that in these series of studies observation times appeared to play no real role in determining perception of distance. This finding raises the question of whether or not representational encoding of the optical variables is employed to generate the visual traces believed to be used in the response task. This is interesting especially considering the current findings indicate that there was no impact of simulated speed s_{Simu} on perceived angular declination that wasn't negated by the impact of training. In sum, it seems that training is, at a minimum, richly supplementing perception, but may obviate the need for mental representations or motor programs altogether. The current findings do not build a strong case for the necessity of motor programs or mental representations during perceptual processes. The main constraint of the current procedure was the methodological necessity of the use of the blind rope-pulling response. This response measure was the factor that required the inclusion of practice trials within the experimental design. Therefore, it is possible that the response measure itself is perhaps not the ideal response measure as we had hoped. While the blind rope-pulling task is similar to blind walking in its cyclic nature of motion, it may not be similar in amount of effort cognitively and physically allocated to reproduce the distances observed.

Limitations and Future Directions

During the reproduction of the observed distances it was assumed that participants engaged their motor programs for the purposes of using it to guide them in rope pulling. However, once engaged in the task of distance reproduction the participant now also has to take account of the actual effort expended in reproducing the distance while also attempting to keep track of where his/her limbs are in relation to the torso, and all this while attempting to update their progress according to their generated motor program. This is arguably a more difficult task and may result in a cognitive distraction that allows for the decay of information from the motor simulation, or may even prompt the observer to abandon motor simulations altogether as the two compete for the observer’s attention and maintenance. Our results suggest that this may be the case, as the only indication we observed which implied that participants may have formed mental simulations for producing the distance was the interaction we saw between training, the actual angular declination, and the angle of declination corresponding to the distance as would be observed on the flat horizontal ground (α). This finding is not surprising in light of the fact that participants practiced on a horizontal terrain with distances similar to those utilized in the experiment. This makes it possible that participants used their memory of the horizontal terrain in forming their mental representations to be used in their estimates of distance on the sloped surfaces. In addition to this, all participants who underwent training also received a recalibration trial between the 7th and 8th trials. And since this recalibration trial was of the furthest distance, it is possible that knowledge of its distance, via feedback provided by the researchers, could possibly set boundaries for the participant to use as a guideline or boundary for effort during the remainder of the trials. Additionally, because we often traverse through an artificially horizontal world when in urban environments, we may be able to effectively imagine distances on a horizontal surface up to a certain extent, perhaps around the 30 degree range where it begins to become necessary to assume a quadrupedal stance to traverse a slope. It would be interesting to perform the same set of experiments on slopes of steeper grades to see if there is a point at which it becomes difficult to utilize the nonvisual cue of α in making these types of distance estimates.

While we made every attempt to control for as many confounds as possible, no study is without its constraints, which allow for alternative explanations, and this study is no different. The major shortcoming of this experiment is that the response measure used has introduced the possibility of other influences caused by the training procedure which was found to be necessary for the generation of accurate responses. This is unfortunate as we had determined that we could not use a traditional blind-walking response because we felt that the participants’ safety would be compromised while trying to walk blindfolded up hills, and we wanted to avoid having to resort to a pantomime blind-walking technique as well. Blind rope-pulling seemed like the perfect solution to the problem because it could be done accurately and it included a cyclic hand-over-hand motion that is similar to the cyclic motion of walking. But perhaps it is not necessary to reproduce the cyclic motion of walking. Instead our future investigation could utilize a different technique that is still relevant to distance but which is not so unusual to participants' experiences that they require training to perform it accurately. Beanbag tossing may prove to be the most appropriate and safe response measure for this type of experiment. With this paradigm it would even be plausible to manipulate perceived and expended effort by varying the weight of the bags participants would use to reproduce the distance viewed. For instance, we could have them hold heavy bags and then throw with lighter bags, expecting to see overthrows, and then have them view it holding lighter bags and then have them reproduce with heavy bags. In this paradigm the control condition would involve participants viewing distances and throwing to reproduce the distance with the same weight of bag (either heavy or light depending on the participants' assignment). The only foreseeable downside to this paradigm is that it is hard to predict whether or not participants would have to spend much time generating a motor program for throwing since the range of motion for a throwing arm is mechanically limited. However, as participants would be required to estimate how much effort to apply to a given throw to reproduce a given distance, it is still possible that a motor program may be employed to the task.

Another option for future exploration may be to induce fatigue in the participants. By having participants run on a treadmill or pedal on a stationary bike for a length of time suitable to induce fatigue we could compare their scores with those of participants who experienced no physical exertion during the experiment. If an observer’s internal state has any impact upon their perception of distance it is reasonable to expect that individuals experiencing exhaustion would perceive distances to be greater than they really are. The beanbag response technique would pair well with this manipulation as it avoids any influence that may be inherent to the fatigue of the legs during the response (e.g., continued walking during the response phase could serve to further fatigue the participant). However, a direct comparison between beanbag throwing and blind-walking on the horizontal zero degree slope condition would be interesting, as it would shed light onto any similarities in response accuracy and whether or not fatigue from walking impacts the two in the same fashion. After all, it may be the case that fatigue of the legs and cardiovascular system has little bearing on one’s ability to throw an object. Additionally, it might also be interesting to induce the sense of physical exertion in the participants by injecting some participants with a small dose of epinephrine to increase heart rate and respiration to determine if these biological cues of effort alone are enough to induce any effect on perceived distance. This manipulation could be included within the beanbag design mentioned above as another condition of manipulation.

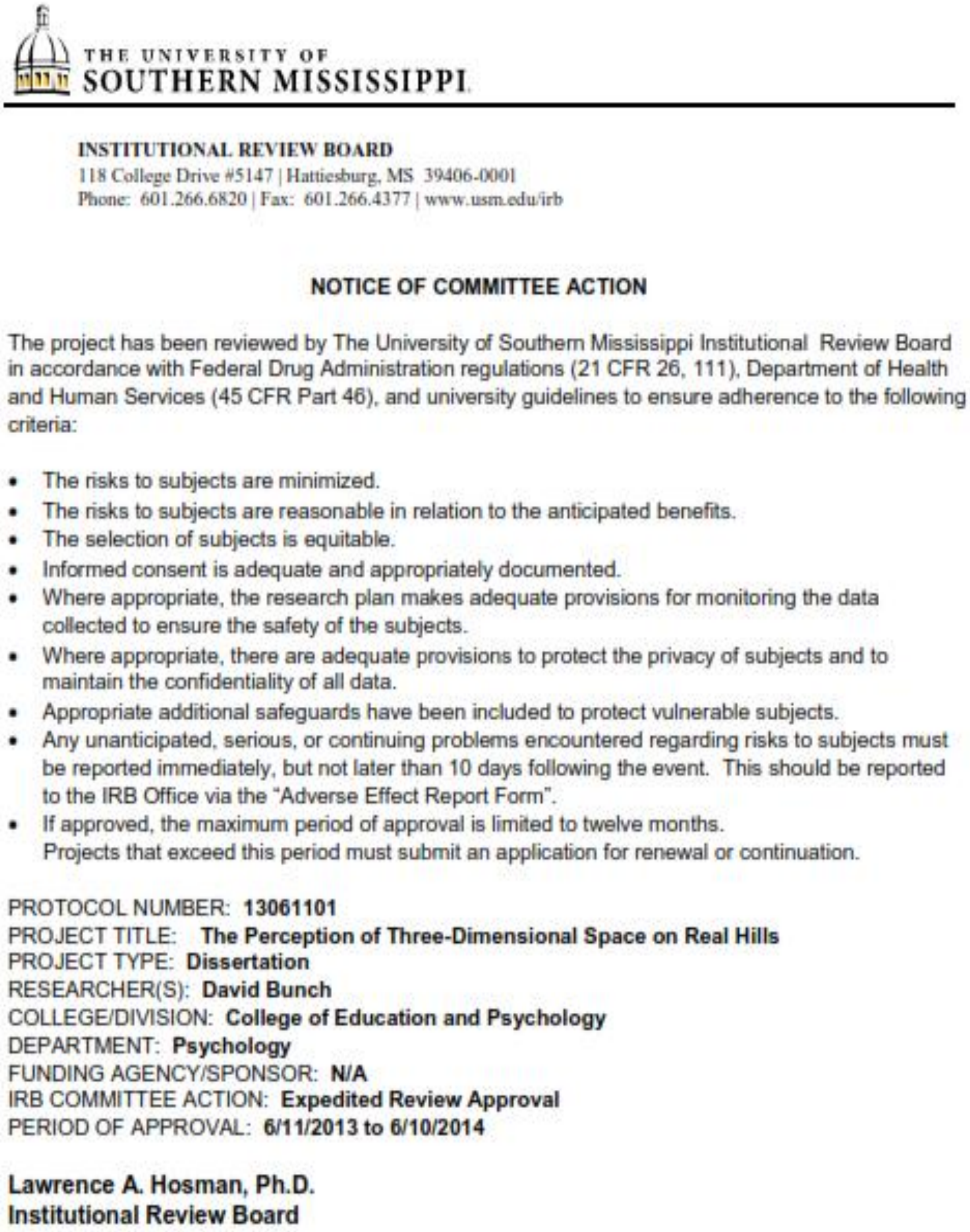
Potential Applications

Understanding the interaction of effort on visual perception and locomotive response planning is important for the purposes of designing urban environments that are as functional and user-friendly as possible as well as for the safety of the individuals, such as construction workers, designing our urban environments (Hsiao & Simeonov, 2001; Simeonov, Hsiao, Dotson, & Ammons, 2003). It is well and good to design a wheelchair ramp that is functional, but if the sight of the incline psychologically defeats the user such that he never attempts to surmount the ramp, then our efforts are wasted as we have only offered a cruel enticement for a fellow human who is still prevented shared access to facilities. Therefore, the more we learn about the impact that observers bring to the task of observation, the better able we will be to produce environments that are safe and useful for those it is designed to service.

Conclusions

The results of this investigation indicated that the amount of time spent looking at the distance between an observer and an object does not impact one's ability to reproduce that distance. This contradicts the representational account that observation time is spent generating motor programs to accomplish the response task. Additionally, simulated speed s_{Simu} had no real impact on perceived angular declination that was not subsumed by the influence of training. However, there was a positive interaction among training, actual effort, and nonvisible optics, which would indicate that the observer utilized nonvisible optics (α) in generating a response. Since α was not visible on the slope conditions, it would seem that perhaps a cognitive representation of a different sort may have been at play, one that has plagued us since the Hajnal et al. (2014) study. Namely, that the observers still appear to be able to utilize a previously seen horizontal surface in making their distance estimates. Taken together, this could present a compromise between the representational accounts and the direct perception accounts of distance perception. The data indicate that it is possible that during training the participants generate a template space, a backdrop or canvas of sorts, that serves as a cognitive representation of a horizontal surface. Then during observation the participants may be able to essentially “paint” the image directly from visual perception onto their cognitive representation of the space they have practiced with. For this sort of task then, practice really does make perfect. This study also makes it clear that in order to tease apart the role of effort in perception, it will be necessary to replicate the current study under different conditions. Particularly, our next investigation should endeavor to investigate effort by directly manipulating the level of fatigue participants are under while engaged in the experiment. Additionally, using a response task that requires no training, perhaps beanbag tossing, might prove beneficial for attempting to look at the direct link between perception and action, that is, the observation and reproduction of a given distance on a given slope. We have discovered a few things, and also generated a few new questions. If anything, this does prove that the scientific study of perception is not as easy as it looks.

APPENDIX A
INSTITUTIONAL REVIEW BOARD APPROVAL



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NOTICE OF COMMITTEE ACTION

The project has been reviewed by The University of Southern Mississippi Institutional Review Board in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services (45 CFR Part 46), and university guidelines to ensure adherence to the following criteria:

- The risks to subjects are minimized.
- The risks to subjects are reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered regarding risks to subjects must be reported immediately, but not later than 10 days following the event. This should be reported to the IRB Office via the "Adverse Effect Report Form".
- If approved, the maximum period of approval is limited to twelve months.
  Projects that exceed this period must submit an application for renewal or continuation.

PROTOCOL NUMBER: **13061101**
PROJECT TITLE: **The Perception of Three-Dimensional Space on Real Hills**
PROJECT TYPE: **Dissertation**
RESEARCHER(S): **David Bunch**
COLLEGE/DIVISION: **College of Education and Psychology**
DEPARTMENT: **Psychology**
FUNDING AGENCY/SPONSOR: **N/A**
IRB COMMITTEE ACTION: **Expedited Review Approval**
PERIOD OF APPROVAL: **6/11/2013 to 6/10/2014**

Lawrence A. Hosman, Ph.D.
Institutional Review Board

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