THE ROLE OF ENERGETIC RESOURCES ON PERCEPTION AND PHYSICAL ACTIVITY CHOICES

by

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ABSTRACT

Observations of human behaviour show a tendency for avoiding energy expenditure through stair climbing where possible. Similarities between demographic influences in stair avoidance and explicit perceptions of geographical slant outlined in the 'economy of action' account (Proffitt, 2006) suggest that this avoidance behaviour might be due to a perceptual bias. Chapter two of this thesis investigated measures of slant perception linked to action. It appears that these 'haptic' measures tap into a perceptual process that is more in touch with the physical reality of the environment than conscious awareness. Chapter four demonstrated that fundamentals of the economy of action account generalise to the perception of staircases, and to a newly developed laboratory setting. Depletion of energetic resources, manipulated through fatigue, resulted in steeper explicit estimates of staircase steepness. In reaction to published criticisms of the methodology used in this field, chapter five took a new approach to testing the effect of resources on perception. Two quasi-experimental field studies, designed to circumvent methodological issues challenging the validity of previous studies, demonstrated that available energy resources affects consciously perceived steepness in the built environment. Chapters six and seven built on this by testing the economy of action account as a model that explains stair avoidance behaviour. Encouragingly, across two different points-of-choice between stair climbing and avoidance, explicit measures of perceived geographical slant were linked to reported prior stair climbing behaviour at one site (chapter six) and objectively measured behaviour at another (chapter seven). Collectively, these findings suggest that available energetic resources dictate the exaggeration of perceived geographical slant experienced at an individual level, and that this in turn influences stair choice behaviour, biasing those with less resources towards stair avoidance and energy preservation.

DEDICATION

To mum.

ACKNOWLEDGMENTS

My primary gratitude is reserved for my academic supervisor, Dr. Frank Eves, firstly for encouraging me to tackle a PhD, and then for his continued support throughout my journey. To have been able to absorb so much knowledge from you over four years is something for which I feel immensely privileged. I must also thank my second supervisor, Dr. Mike White, who has always been there to answer my queries, no matter how ridiculous or impossible that might have been to answer in some cases. I have no room to thank all the other great members of staff from this university, past and present, who have helped me along the way, but your generosities will not be forgotten. To my army of project students, without your efforts none of this would have been possible, your tireless work in collecting monumental amounts of data ensures that should we ever cross paths again, the drinks are on me. Those unfortunate friends of mine that endured living with me throughout this time, the raddlebarn lads, Kev & Steph, and Nathaniel, who let me crash in his slug infested spare room when money was tight, thank you all for your support. My PhD brothers, in both Birmingham and Hong Kong, especially those in the sportex football team – we did it lads! Finally, there are no words to express how grateful I am to the support of my family since I took on this challenge, you always believed in me and were never too far away when I needed you.

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LIST OF PUBLICATIONS

The following six empirical papers form the basis of this thesis:

Taylor-Covill, G. A. H., & Eves, F. F. (2013). The accuracy of 'haptically' perceived geographical slant perception. *Acta Psychologica, 144,*444-450.

Taylor-Covill, G. A. H., & Eves, F. F. (2013). What do hands know about objects? Taking perception of hills out of context. *Acta Psychologica, 144,* 459-461.

Taylor-Covill, G. A. H., & Eves, F. F. (2013). Slant perception for stairs and screens: Effects of sex and fatigue in a laboratory environment. *Perception, 42,* 459-469.

Taylor-Covill, G. A. H., & Eves, F. F. (under review). When what we need influences what we see: Choice of energetic replenishment is linked with perceived steepness. *Journal of Experimental Psychology: Human Perception and Performance.*

Taylor-Covill, G. A. H., & Eves, F. F. (submitted). Reported stair climbing behaviour predicts perception of steepness. *Perception.*

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During the period of postgraduate study at the University of Birmingham the following paper was also submitted:

Eves, F. F., Taylor-Covill, G. A. H. & Thorpe, S. K. S. (under review). Perceived steepness can deter stair climbing when an alternative is available. *Psychonomic Bulletin and Review.*

CHAPTER 1

INTRODUCTION

1.0 Introduction

1.1 The obesity problem

Obesity poses such a serious threat to public health that it has been discussed as 'an epidemic' (Gard & Wright, 2005). The explosion of population level obesity through the late 1990s has since slowed, however, rates continue to rise despite large injections of public spending (Malik, Willet & Hu, 2013). Moreover, obesity is becoming prevalent across the entire developed world, and is no longer an issue faced by only a select few of the wealthiest nations (Hill, Peters, Catenacci, & Wyatt, 2008).

The most recent available data for England showed that in 2011, 65% of men, and 58% of women, were classified as overweight (BMI ≥ 25) or obese (BMI ≥ 30) (Health Survey of England, 2011). Figure 1.1 displays the trend of an increasingly overweight/obese population in England. McPherson, Marsh, & Brown (2007) drew predictions from available data up until 2007 calculating that by 2050 nine out of every ten men and eight out of every ten women will be overweight or obese.

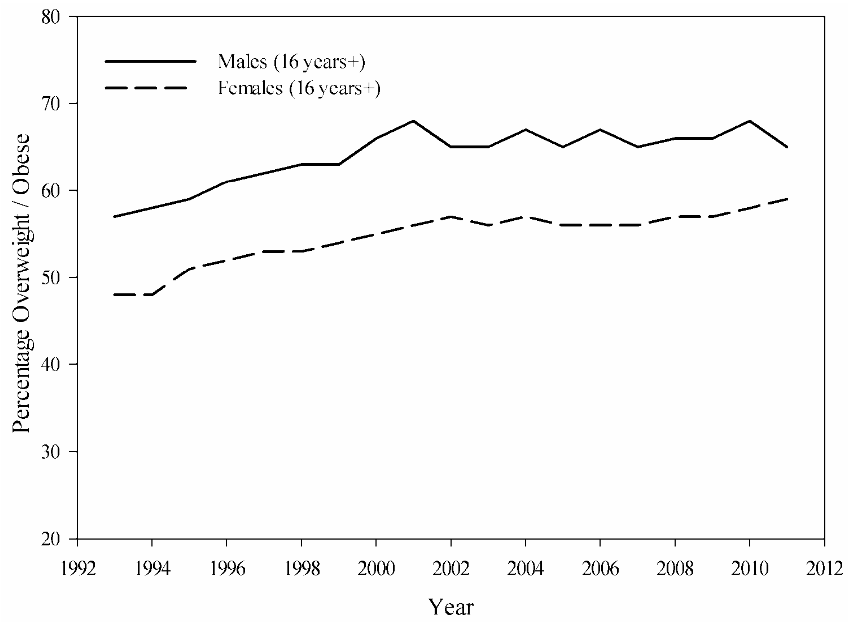

Figure 1.1. Percentages of men and women in the UK classified as overweight or obese between 1993 and 2011 (Health Survey of England, 2011).

1.2 An unhealthy environment

The working environment of the 21st century has developed in such a way that fosters obesity as a public health threat (Pearce & Witten, 2010). In the United Kingdom, prior to the industrial revolution, agriculture provided the majority of its citizens with employment. The manual tasks involved with farm-work incur roughly four times the energy expenditure of rest (Brun et al., 1979; McArdle, Katch & Katch, 1981). A shift towards manufacturing industries began in the late 19th century. While generally more strenuous than farm work, factor work tasks still reflect a moderate level of physical exertion (McArdle, Katch & Katch, 1981; Pernold et al., 2002). Through the late 1900s, the service industry became the dominant workplace (figure 1.2), increasing concurrently with levels of obesity (figure 1.1). Work in this sector is mostly of a sedentary nature. For example, office work incurs an estimated energy expenditure of only 1.34 METs[1] (Kuriyan, Easwaran & Kurpad, 2006). It is possible that the moderate energy expenditure associated with the occupational activities of the past was sufficient in preventing obesity. Recent evidence suggests that the increased prevalence of occupational sitting time associated with office work directly contributes to the obesity risk of the working population (Choi, et al., 2010; Mummery et al., 2005).

Changes to the physical environment are also likely to have contributed to rising obesity. Recent decades have seen an increase in motorised transport links that have led to the development of what King refers to as ‘car-oriented environments’ in urban sprawl areas of major cities (King et al., 2002). The average BMI of residents in such suburban areas, where planning is focussed on automobile links to centres of interest rather than those accessible to pedestrians or cyclists, is higher than in inner-city areas

[1] METs is defined as ‘Metabolic equivalents,’ the associated energy expenditure of activity relative to complete rest, which would be 1 MET.

(Frank, Andersen & Schmid, 2004). This is likely to be a result of a lack of active commuting and increased reliance on cars for journeys which could be within reach of active transport, but are far more suited to motorised alternatives (Sallis et al., 2004).

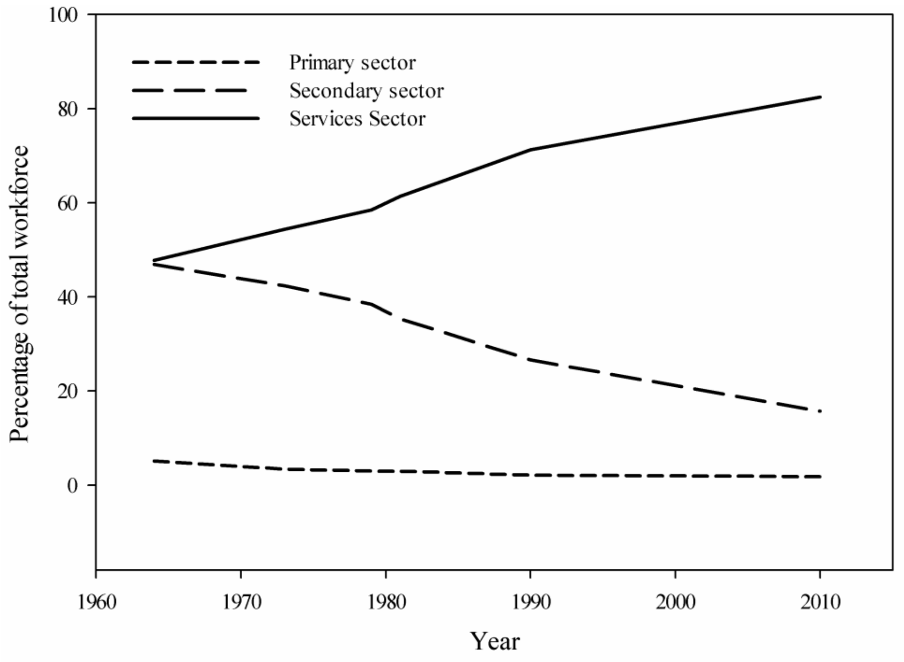

Figure 1.2. Percentages of UK workforce by sector between 1964 and 2010 (ONS, 2010).

1.3 Energy Balance

Humans, like all living systems, function at their optima when energy expenditure is equivalent to energy intake. This relationship, termed *energy balance*, is defined by the laws of thermodynamics such that energy is transferred between entities rather than energy being systematically created and destroyed. Energy intake comes in one form, diet, making it relatively easy to calculate. Energy expenditure however, can be split into three forms; basal metabolic rate (BMR), the thermogenic effect of feeding (TEF), and physical activity (PA). BMR refers to the energy used to maintain bodily functioning during complete rest, processes such as cell respiration, blood circulation, sympathetic nerve activity and so on. TEF represents the increased energy expenditure above BMR required to consume and breakdown food. PA can be split into two sub-types, exercise-related activity thermogenesis (ERAT), and non-exercise activity thermogenesis (NEAT) (Levine, 2002). ERAT refers to planned exercise activities such as going to the gym and playing sports. NEAT refers to everything we do, excluding ERAT, which is not eating or sleeping. NEAT includes activity such as walking between rooms, occupational activity, fidgeting, gardening, and sexual intercourse. This group of behaviours accounts for the vast majority of the daily energy expenditure generated through PA, even in physically active sportspeople (Levine, 2004). Importantly, because in most cases NEAT behaviours are not consciously perceived as exercise, we are far less aware of the amount of energy we expend from these activities (Levine, 2004). This makes the daily management of energy balance at a personal level a quite formidable task.

Energy expenditure in humans is calculated by the amount of heat energy released per unit of time. Over a 24 hour period, BMR is estimated to account for 75% of total energy expenditure (Ravussin et al., 1988). The thermogenic effect of food means that 10% of all energy supplied by dietary intake is burnt off by processes associated with its consumption and digestion (Tappy, 1996). This leaves just 15% of our energy intake to be regulated through PA in order to avoid a 'positive energy imbalance.' This occurs when energy intake is not fully offset by necessary energy expenditure. Over time, positive energy imbalance is the primary cause of most cases of obesity. Unused energy must go somewhere, and the body's solution is to store this surplus energy in adipose tissue as bodyfat so it can later be used as energy (Kershaw & Flier, 2004). Increased bodyfat to the level of obesity makes individuals with a BMI above 30 more susceptible to the development of type 2 diabetes, stroke, certain cancers, heart and liver disease, and osteoporosis (Kopelman, 2007).

1.3.1 *Energy minimisation in locomotion*

Natural selection dictates that organisms most adept at preserving their energy stores have a greater chance of survival through periods of depleted available resources (Darwin, 1859). Consistent with this premise, energy minimisation is central of all locomotor behaviours that take place under no time pressure or the presence of an environmental threat such as a nearby predator (Alexander, 2003). In humans, young adults tend to have a 'default' walking pace of roughly 1.5 m/s, a speed that minimises energy expenditure (Wirtz & Ries, 1992). Although with age, humans walk slower (Bohannon, 1997), overweight and obese individuals continue to walk at similar speeds to their leaner counterparts (Browning, Baker, Heron & Kram, 2006). Nonetheless, the metabolic output for an obese walker is 11% higher than that of a healthy weight walker (Browning & Kram, 2005).

Regardless of size, when our locomotive speed increases, we adjust our pattern on movement in such a way that keeps energy expenditure to a minimum, these adjustments are referred to as 'gait changes.' Walking at increased speeds involves a proportional increases in stride length, while stride frequency remains constant (Holt, Hamill, & Andres, 1991; Holt, Jeng, Ratcliffe, & Hamill, 1995). Experimental evidence shows that we only move from walking to running when a speed is reached that would be more efficiently executed by the running stride pattern (Cavanagh & Williams, 1982). Consistent with a universal model of energy minimisation, using motorised treadmill set-ups, researchers have observed similar patterns of gait change in the ostrich (Rubenson, Heliams, Lloyd & Fournier, 2004), horses (Holt & Taylor, 1981), rodents (Hoyt & Kenagy, 1984), lizards (Garland, 1994; Reiley, McElroy, Orum & Hornyak, 2006), and hexapod insects (Niishi, 2000). Furthermore, observations suggest that animals minimise the costs of transport by selecting the most energy efficient routes of travel. Wall, Douglas-Hamilton, & Vollrath (2006) showed that elephants avoid climbing even when the hill terrain offers significant vegetation on which they could forage. Similarly, Thorpe, Crompton, & Alexander (2007) have shown that orangutans avoid climbing trees or jumping between trees to forage, preferring to swing the branches they are on, using that momentum to throw them onto a neighbouring branch.

While energy minimisation during locomotion is undoubtedly a crucial requisite for survival of other animals, I argue that for many humans living in the developed world, processes that drive energy minimisation might contribute to a health risk.

1.3.2 *The issue with humans*

Processes that maintain energy balance in humans can be summarised as 'biological homeostasis' (Talwar & Strivastava, 2003). Energy intake is regulated through appetite, primarily by the hypothalamus, but also through peripheral signals from the digestive tract, adipose tissue and the pancreas (Stanley, Wynne, McGowen & Bloom, 2005). These genetically ancient processes are hard-wired to pressure us into maintaining energy uptake such that we experience significant somatic signals such as hunger pangs when we go without food for as little as 12 hours (Carlson, 1931). When it comes to energy output, however, no such process pressures us into staying active. In fact, the majority of our PA behaviour is implicitly regulated to ensure work is done at the minima of energy expenditure, perhaps because the majority of our genetic material stems from hominids that were more likely to encounter issues of negative energy imbalance than the issue of a positive one. Many of our hunter-gatherer ancestors would have endured significant bouts of energy expenditure in order to obtain food. In the developed world, however, food is freely available. Drive-thru restaurants are increasingly common, and supermarkets now deliver to people's homes.

Currently, the availability of food in the western world outweighs the daily calorific needs of the individuals residing within it. In the United Kingdom, food supply per capita is above 3,400 calories per day (FAOSTAT, 2009), a dietary intake higher than what is recommended for physically active male weighing 100kg (DOH, 2011a). Even if an unprecedented food shortage was to occur in a western nation, lean individuals store up to two months worth of the energy required to maintain BMR in adipose tissue, making starvation in the developed nations highly unlikely. Evolution might not be fast enough to adapt to the sudden changes in our environment that have developed to foster the risk of a long-term positive energy imbalance, hence, nearly all humans residing in the developed world are at risk of obesity.

Achieving energy balance when living in the developed world can be challenging, however, population level research suggests that only small increases in daily PA are required to address the rise in population weight. Hill, Wyatt, Reed & Peters (2003) monitored the distribution of weight gain over an eight-year period for two large adult cohort samples, observing an average increase in weight of roughly 15lb. The authors calculated that this increase was down to a positive energy imbalance accounted for by a surplus energy intake of as little as 30kcal/day. Even those in the top 10% of weight gain within the sample would only have been ingesting 100kcal/day more than is required to maintain energy balance. Based on this data, Hill suggested that only small increases in daily energy expenditure such as a brisk walk during one's lunch break are required to correct the energy surplus that causes obesity. In line with such findings, the Department of Health in the United Kingdom have suggested that a downward shift of 100kcal/day in energy intake would be sufficient to ‘reverse’ the current trend of increased obesity in the UK (DOH, 2009).

1.4 Stair climbing

Stairs are encountered on a regular basis while navigating the built environment. Opportunities for stair climbing occur most frequently at home, the workplace, in shopping malls, or train and subway stations. The majority of inhabitants of the developed world will encounter opportunities for stair climbing multiple times each day, making stair climbing an easily incorporable addition to daily energy expenditure.

Stair climbing is the most vigorous form of a class of behaviours termed ‘lifestyle physical activity’ - exercise that takes place during day-to-day activity, or ‘NEAT’ (Levine, 2002). Bassett et al. (1997) tested the energy expenditure of stair climbing with physically active participants through the measurement of cardiovascular outputs during stair climbing on a motorised escalator. They calculated energy expenditure to be 8.6 times that of rest, an intensity higher than that of cycling to work or playing tennis (see figure 1.3). More recent investigations, however, have suggested that Bassett and colleagues’ calculation might be an underestimate. Teh & Aziz (2002) used a larger sample of participants, some of whom were not physically active, and measured the energy expenditure of stair climbing using lightweight spirometry systems in a field setting to enhance ecological validity. This allowed participants to climb at their natural pace rather than having to keep in time with a motorised escalator. The authors calculated that stair climbing incurred 9.6 times the energy expenditure of rest, an intensity more similar to competitive sporting activity such as a soccer match.

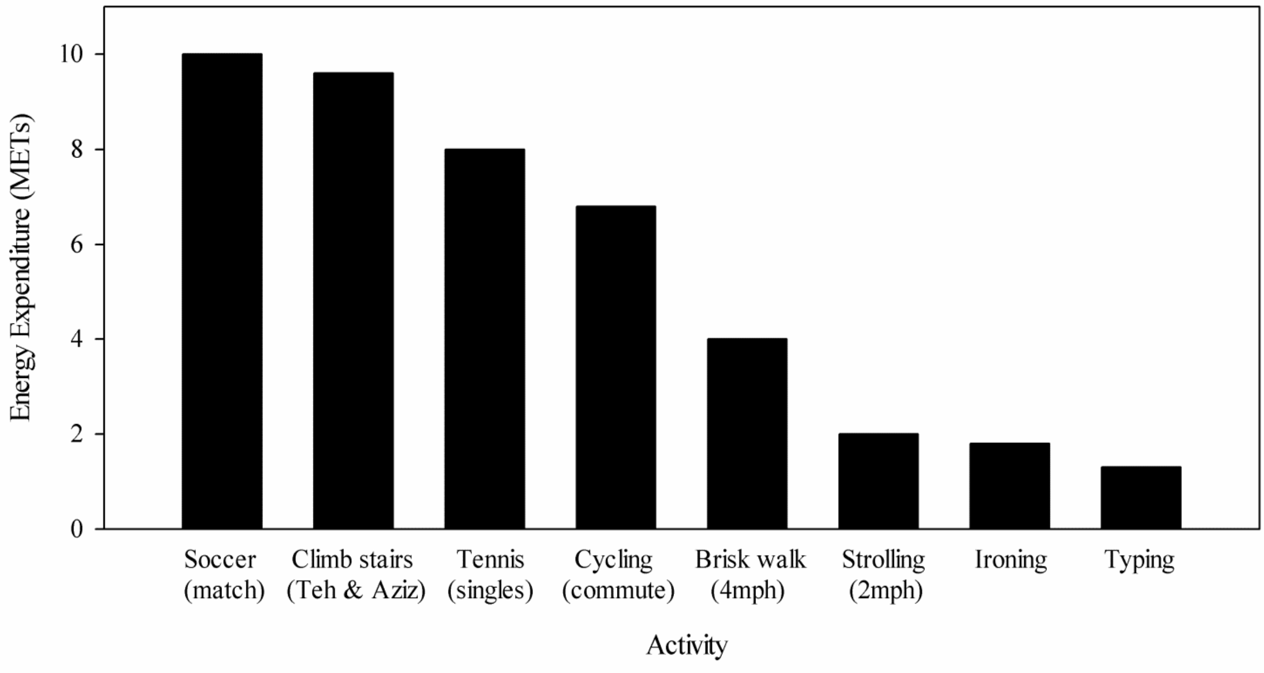

Figure 1.3. The related energy expenditure of different sporting, exercise and lifestyle activities (Ainsworth et al., 2011; Teh & Aziz, 2002).

1.4.1 *Health benefits of stair climbing*

Current physical activity recommendations emphasise the accumulation of activity throughout daily living (DOH, 2011b), and stair climbing has been acknowledged as an ideal means by which the general public can achieve this goal (DOH, 2004). For individuals without the time, or confidence, to keep physically active by going to the gym, stair climbing offers a freely available alternative that can become part of the daily routine. Evidence suggests that increasing one's daily stair climbing improves a number of health factors. For example, Boreham, Wallace, & Nevill (2000) found that following a seven week intervention to increase bouts of stair climbing throughout the day, previously sedentary females showed significant improvement in their cardiovascular fitness (17.7%). In a follow-up study, a similar intervention produced significant improvement in lipid profiles with an observed reduction in high-density lipoprotein cholesterol of 7.7% (Boreham et al., 2005). Stair climbing may also help prevent the development of osteoporosis, which is caused by a fall in bone mineral density (BMD). Coupland et al. (2005) showed that the reported daily stair climbing frequency was the strongest predictor of BMD measurements in a sample of 580 post-menopausal women. The authors suggested that the high intensity nature of stair climbing exercise has a preventative effect on the development of the condition.

1.4.2 *Determinants of stair avoidance*

Given our predisposition for minimising energy expenditure, and the high energy cost of stair climbing, it is not surprising that we avoid this energy costly behaviour when energy-free alternatives such escalators or lifts are directly available. In these contexts, referred to as stair climbing 'points-of-choice,' stair avoidance is the preferred behaviour in the majority of settings (Eves, in press). There are, however, a number of factors that directly influence the likelihood of stair climbing over motorised alternatives.

1.4.2.1 *Situational factors*

In line with energy minimisation, the height of the climb affects the likelihood of pedestrians climbing stairs. Eves & Webb (2006) showed that the number of steps associated with a given climb was negatively correlated with the rate of stair climbing in both workplace and public access settings. This would suggest that pedestrians *sense* the energy consequences associated with a given climb while approaching a point-of-choice, allowing them to consciously avoid more costly staircases when a motorised alternative is available.

As reviewed by Eves (in press), the context in which we encounter a point-of-choice is also important. When under time-pressure, stair climbing will often be the quickest route out of a building. In train and subway stations, where pedestrians are more likely to be under pressure to exit quickly, escalators can become overcrowded with a queue forming at the base, making stair climbing the quicker option of exit. Likewise, waiting for a lift will generally incur some time cost. However, in shopping centres and airports, pedestrians are rarely in a rush, so waiting for a lift becomes less of an issue. Furthermore, unlike train and subway stations, pedestrians will not approach points-of-choice in 'waves' as they leave a train, meaning escalators will rarely be crowded. These contextual differences are likely the reason for stair climbing in airports and shopping malls rarely exceeding 5% of the observed pedestrian behaviour (Coleman & Gonzalez, 2001; Kerr, Eves & Carroll, 2001), while in train stations, the rate is much higher at around 20% (Lewis & Eves, 2012).

Not only the physical and social properties of the environment influence stair choice, the climatic environment also appears influential. In Eves & Masters' (2006) study of stair climbing behaviour on the mid-levels escalator system in Hong Kong a significant influence of humidity was uncovered on stair climbing behaviour. The authors observed that the rate of stair climbing decreased as humidity levels increased. Eves & Masters directed readers to a study by Sheffield-Moore et al., (1997) that showed when humidity levels are higher, perceived exertion and discomfort levels during physical activity increase at a higher rate than when humidity is lower, even when temperature remains remained the same. This negative affective response to exercise in high-humidity climates is likely the cause of reduced stair climbing seen in Hong Kong. Crucially, Eves & Masters was found humidity only influenced stair climbing behaviour of non-Asian pedestrians. This suggests that pedestrians who were less acclimatised to the high-humidity environment were more affected by this factor than the native pedestrians.

1.4.2.2 *Demographic factors*

For some people, stair climbing is the only form of 'vigorous' physical activity they take part in, as such, there are vast differences in the ease of climbing between individuals based on their cardiovascular fitness, leg strength, flexibility, and even leg length can be important. Certain demographic groupings are more likely to possess the physical attributes that make stair climbing a more bearable task, and behavioural observations support the notion that this makes them more likely to climb stairs.

In a recent review of demographic influences on stair choice behaviour, Eves (in press) presented data from 43 studies that coded pedestrians for their choice of stair climbing, or taking an escalator, while also noting; sex (male vs. female), age (old vs. young), weight (healthy weight vs. overweight), or a combination of these factors. Analyses were conducted for contexts without time pressure, such as shopping malls, separately from those with time pressure, such as train stations. Results were consistent across context. Females avoided the stairs significantly more than men, the elderly more than the young, and those coded as overweight more than those coded as a healthy weight.

The observed behaviour is in fit with an account of energy minimisation. Climbing a given staircase would require a larger proportion of the energy stores of a woman than a man. Men have a physiological advantage over women such that they possess a larger cardiovascular system relative to their bodysize (McArdle, Katch, & Katch, 1981), have greater leg strength than women (Miller et al., 1993), and carry less dead weight in the form of bodyfat (Taylor et al., 1997). Similarly, elderly people will use more of their relative energy resources to climb a given staircase relative to young people because cardiovascular fitness and muscular strength decline with age (Lindle et al., 1997). Finally, since stair climbing requires work done against gravity, the amount of dead weight one carries in the form of bodyfat directly influences the total energy expenditure required to climb a given flight of stairs (Weinsier et al., 2000). This makes climbing a particularly energy-hungry behaviour for overweight pedestrians, which explains why they consistently avoid the stairs more than those of a healthier weight status.

1.4.2.3 *The presence of bags*

In direct similarity to pedestrians carrying more weight in the form of bodyfat being more likely to avoid stair climbing, the same is true for pedestrians carrying extra weight in the form of heavy bags. In the same review conducted on demographic influences on stair choice, Eves (in press) showed that pedestrians coded as carrying heavy bags, or wearing a large backpack, were significantly more likely to avoid climbing stairs than unencumbered individuals. In 14 of 17 reviewed studies that coded pedestrians for the presence of heavy bags, this effect was observed to be independent of demographic influences of stair choice in multivariate analyses, suggesting an additive effect of the presence of bags on stair avoidance.

1.5 Visual Perception

Visual perception refers to the collection and interpretation of environmental information supplied to the visual system through visible light. What we perceive, however, is rarely a literal image of what is projected onto the retina. Neural processing turns a retinal image into visual ‘perception’ from the visual information available. The information that is of the most relevance to the perceiver will directly what is perceived from the visual scene. Hence, visual perception is influenced by body-size (Stefanucci

& Geuss 2009; van der Hoort, Guterstam, & Ehresson, 2011), race or cultural background (Segall, Campbell & Herskovits, 1966), sex (McGuiness & Pribram, 1979; Postma, Izendoorn & De Haan, 1998), and physical fitness (Bhalla & Proffitt, 1999). Visual perception can also be affected in the short term by malleable factors such as our personal goals (Balcetis & Dunning, 2002), level of fatigue (Bhalla & Proffitt, 1999), emotional state (Riener, Stefanucci, Proffitt & Clore), and the social context (Schnall, Harber, Stefanucci & Proffitt, 2008).

1.5.1 *Ecological Approach to Visual Perception*

The ecological account of visual perception was developed by J. J. Gibson (1950, 1966, 1979). Previous theorists of visual perception worked mainly on the assumption that visual perception involved complex computations of cues from the environment in order to *construct* an image of the world around us. Gibson's framework, however, emphasised the richness of available information in the optic array, and contends that this information is directly perceived so that perception is optimised for the guidance of action. Ambient information comes from what Gibson terms 'invariants.' These higher-order variables allow the perceiver to see the environment in terms of its size and location relative to themselves, a function that serves action. For example, Gibson emphasised texture gradients as invariants for depth with motion of the observer and viewing angle. Texture gradients provide us with a direct source of information about the distance and orientation of a surface relative to our position. Individual elements of texture that are more closely spaced when further away and widen are the draw nearer. During forward motion, the rate at which these elements of texture become more widely spaced provides us with information about their distance relative to elements of texture closer to us (Gibson, & Cornsweet, 1952).

Gibson suggests that action without perception would be unguided, and perception without a means for action of no use to the animal, so rather than acting on a constructed image, the animal and the environment are intimately linked such that we interact with the world around us not always through conscious action planning, but also through automatic adjustments to environmental stimuli (Gibson, 1979). I will present evidence for Gibson's account using one aspect of perception as example, that of 'optic flow.'

The pattern of motion of an observer's field of view generated by movement relative to the surrounding environment, termed 'optic flow,' directly influences both our perceptual experience and our movement. In a classic example, Lishman & Lee (1973) demonstrated optic flow in the 'moving room study.' The authors composed an experimental set-up where participants stepped into a movable room, standing on platform attached to a trolley that could be attached to the room by varying degrees. When the trolley was fixed and the room surrounding the participant moved backwards and forwards, participants demonstrated a sway response in line with changes in forward and backward motion of the room, and reported experiencing a feeling of moving in line with the direction of optic flow supplied to them by the moving room. When the trolley attached to room and the two moved together, creating stable optic flow, participants reported experiencing no feelings of movement whatsoever, but still displayed a sway response in line with movement of the room and trolley (Lishman & Lee, 1973). Prokop, Schubert & Berger (1997) showed that participants walking on a treadmill made automatic adjustments in stride length to match their perceived speed as presented to them by a visual display of optic flow. Despite being told to keep their walking speed constant, forward flow resulted in increased walking speed, and backward flow a decrease. More recently, studies have demonstrated that recalibration with optic flow for a visually guided action is extremely fast. Fajen (2007) manipulated the strength of a brake pedal in a virtually simulated braking task, finding that participants rapidly adjusted the strength of their braking in line with both increases and decreases in brake strength, despite having no idea the strength of their brake pedal was being manipulated. Since available information about how hard to brake would be primarily available from optic flow, Fajen concluded that it provides a source of *online* information about time-to-contact that the visual-motor system can rapidly adapt to.

1.5.2 *Affordances*

An affordance is the quality of an object, or part of environment, that affords a given action (Gibson, 1979). According to Gibson, rather than actively calculating affordances, we directly perceive what an object or the environment *offers* to us in terms of action. Take the example of two builders who are told by their supervisor to take a lunch break. Both men require a rest from their tiresome work, but no seating has been provided at their worksite. One man is particularly tall, at 6ft 6 in height, while the other is short, at 5ft 5. Throughout the day, they have been taking bricks from a stacked pile that was delivered in the morning, so the pile has shortened from its delivery height now standing at a height of just under 6ft. Because the bricks are solid and heavy, the pile *affords* a sturdy surface capable of taking the weight of either man on it or against it. The taller man’s shoulders are around the same height as the pile, so by placing his hands on the top and pushing upward he can gain the adequate leverage needed to push his himself up and swing his torso round in order to sit on top of the stack. The shorter man, however, has to reach up above head height in order to place his hands on top of the pile, meaning he cannot gain the leverage around the shoulders necessary in order to lift himself up and sit on the top. Nonetheless, the stack of bricks is still a sturdy surface that can take his weight against it, so he leans against in order to rest during the break. Both men *see* a pile of bricks, but to the tall man the pile *affords* sitting, while for the short man it *affords* leaning.

Experimental evidence displays a high level of accuracy in perceiving affordances such that we appear to have exact knowledge of what we can and cannot do in terms of interaction with the environment. Warren (1984) demonstrated this in his test of the theory of affordances for stair climbing. Participants were able to detect the critical riser height of steps, i.e. the point at which they are unable to climb using bipedal locomotion, which matched their biomechanical constraints for the task. Participants of differing height all selected a critical riser height that when expressed as a proportion of leg length was at 0.88. Warren (1984) suggested this was an intrinsic metric for perceiving the point at which a stair cannot be scaled by bipedal locomotion. Furthermore, in line with perception fostering energy minimisation, in forced choice trials where participants were asked to select their 'preferred' step to climb, they consistently chose a riser height that matched their minima of energy expenditure during climbing. In echo of Gibson's theory, Warren concluded that critical and optimal values of environmental stimuli were invariants, perceived not in numeric metrics, but as proportions relative to aspects of the body related to associated action.

1.5.3 *The Two-system theory of Visual Perception*

Over the past three decades, advances in neuropsychology have led to huge development in our understanding of the organisation of the human visual system. One of the most notable findings through this period is that cortical processing of visual information is split into two separate pathways, the 'ventral stream' for perception and recognition of a stimulus, and the 'dorsal stream' for locating and interacting with a stimulus (Goodale & Milner, 1992). This model proposes that information received by the visual cortex in the occipital lobe is *streamed* through either the temporal lobe (ventral stream), or the parietal lobe (dorsal stream), dependant on how the perceiver needs to act on the information. This separation is commonly termed a *dissociation* of perception (ventral stream) and action (dorsal stream). Evidence for this model has been demonstrated by neuroimaging studies using PET scanning (Faillenot et al., 1997), and fMRI in humans (Shmuelof & Zohary, 2005). However, it was behavioural experiments on the patient DF that prompted Goodale and Milner to conceive modelling of the visual system in this way.

Patient DF suffered an episode of carbon monoxide poisoning that resulted in a lesion in the occipital cortex. This resulted in poor perception of shape and orientation, but a unique ability to continue with daily tasks. Goodale and Milner were alarmed to DF's strange perceptual tendencies during a preliminary test to determine whether she would be suitable for participation in their experiments. The task involved identifying familiar objects. While struggling to perceive and report a pencil held out in front of her, to the surprise of experimenters, patient DF suddenly picked it up to get a better sense of what the object was. DF's ability to appropriately and naturally grasp an object that she could not recognise suggested fully intact visual-motor abilities without conscious awareness. In the formal experiments that followed, a consistent pattern emerged. Patient DF's ability to identify stimuli was impaired, but interaction was not. This is neatly demonstrated in an experiment that required two tasks involving a card and slot, similar to the situation of posting a letter through a letterbox. Goodale, Milner, Jakobson & Carey (1991) reported that DF could not accurately orientate the card to match a selection of slots that varied between 0° and 150°, however, when asked to post the card through the slot, DF did so with a level of accuracy similar to that of control participants. When it came to the action associated with the card and the slot, DF appeared like anyone with normal vision, however, when consciously matching the card to match the slot's orientation, a lack of ventral stream perception hindered performance.

The separation of visual pathways is essential in understanding dissociations between perception and action related to visual illusions, to which I will turn my attention to now.

1.5.4 *Visual Illusions*

A visual illusion is any visually perceived image that differs from objective reality. This includes not only classical optical illusions commonly depicted in pictures (see figure 1.4), but also natural scenes that do not depict the physical reality of the environment around us.

Visual illusions have been used to demonstrate dissociation between perception and action outlined in the two-system model of visual perception. For example, Jackson & Shaw (2000) showed that participants consistently reported the top line of the *Ponzo illusion* (figure 1.4) to appear longer, however, no differences were found between the grip apertures when participants reached and grasped the two lines that formed the illusion. While the conscious, ventral stream perception was fooled by the illusion, the motor action associated with interacting with lines remained accurate, suggesting that dorsal stream perception *resisted* the visual illusion. Similar patterns of results have been found for various other illusions such as the *Titchner circles illusion* (Aglioti, De Souza & Goodale, 1995) and the *Muller-Lyer illusion* (Daprati & Gentilucci, 1997).

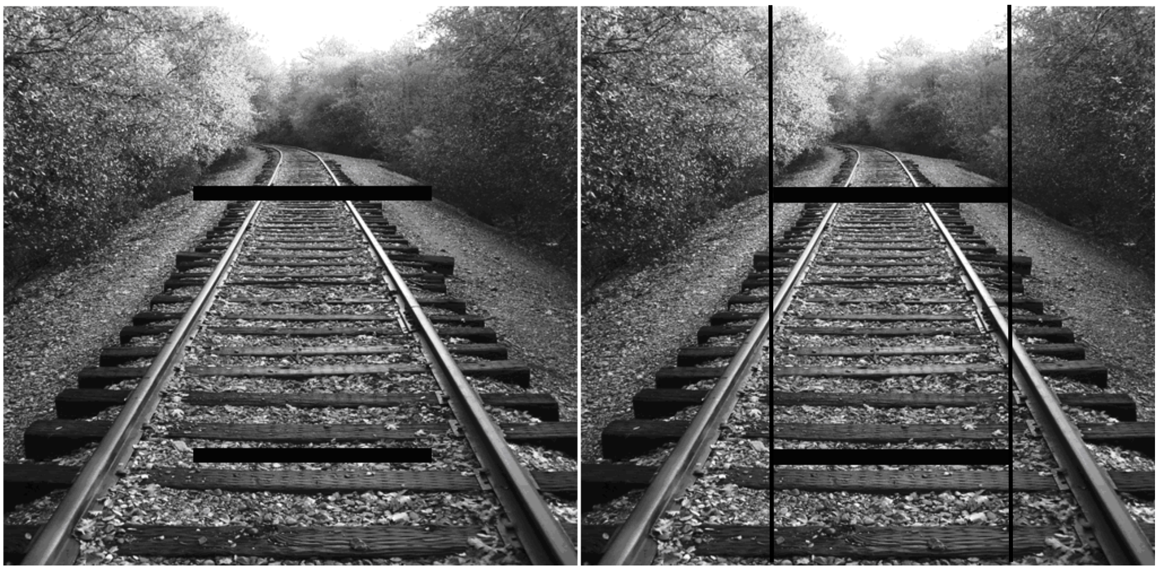

Figure 1.4. The *Ponzo illusion.* A geometrical-optical illusion, first presented by Ponzo (1911). On the left hand side, the top line appears longer due to linear perspective. We perceive the converging sides as parallel lines receding into the distance, so the top line is interpreted as further away and is thus perceived as longer. On the right hand side, additional vertical lines demonstrate that the two horizontal lines are the same size.

Dissociations between perception and action in response to visual illusions are not restricted to studies involving grasping. In a larger experimental set-up that featured a version of the *Muller-Lyer illusion* (Figure 1.5), Wraga, Creem & Proffitt (2000) showed a dissociation between verbal reports of distance (ventral stream), and blindwalking responses (dorsal stream). When stood at the base of the illusion, verbal reports were affected by whether the hoop was presented in or out of the line. However, when participants were blindfolded directly after viewing the illusion and instructed to walk the distance of the line that they had just viewed, blindwalked distances did not differ depending on whether the hoop was presented inside or outside of the line. The authors suggested that standing at the base of the line gave perceivers a reference frame to use in order to accurately interact with the stimulus through blindwalking.

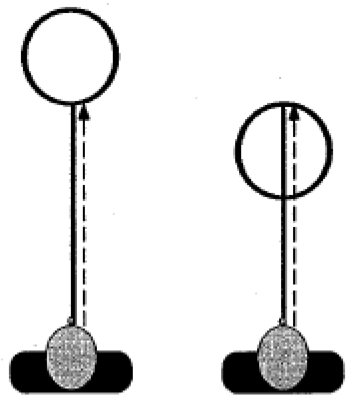

Figure 1.5. A bird's eye view of the two viewing conditions from experiment 2 of Wraga et al. (2000) showing the different presentations of a Muller-Lyer illusion. The 'hoop-out' condition resulted in larger verbal estimates of distance, but there were no differences in blindwalked distances between conditions.

An interesting property of visual illusions is that they have a greater effect on perception when involving real objects, and when they appear outside. Evidence for this stems from investigations into the vertical-horizontal illusion that shows we tend to overestimate vertical lines as greater than horizontal ones. Chapanis & Mankin (1967) showed that the vertical height of various shapes and objects was overestimated more when viewed outdoors relative to indoors. In direct similarity, Yang, Dixon & Proffitt (1999) replicated this finding using single lines as stimuli. When vertical lines (PVC tubes) were presented in a natural environment, overestimation relative to horizontal lines was exaggerated by 12%, an effect greater than that which was observed when participants viewed lines on a computer screen (3%) or in photographs (2%).

1.5.5 *Embodied Perception*

When consciously perceiving the environmental, our body and its action capabilities directly influence visual experience. This is referred to as 'embodied perception.' In a recent example, van der Hoort, Guterstam & Ehrsson (2011) showed that the apparent size of our own body influences how big the world around us appears. The authors manipulated bodysize using a head-mounted display that was linked to a variety of artificial bodies, ranging from a tiny Barbie doll (80cm), to a giant mannequin (400cm). When participants took *ownership* of Barbie's body, objects appeared bigger and further away than in natural conditions, despite identical retinal input, while ownership of the giant's body made objects appear closer and smaller (van der Hoort, Guterstam & Ehrsson, 2011). Bodily abilities do not just affect perception of the world as a whole, but individual objects relevant to action. The perceived size of an oncoming baseball is scaled by a batter's ability to strike it such that stronger hitters perceive the ball as larger (Witt & Proffitt, 2005), and the apparent size of a golf hole is mediated by a golfer's putting ability such that prior success leads to the hole appearing bigger (Witt, Linkenauger, Bakdash, & Proffitt, 2008). The ability to interact with the environment not only affects the perceived size of objects, but also the size of body parts we would use to act upon them. For example, right-handed people perceive their right arm to be longer than their left due to the increased abilities of their right hand (Linkenauger, Witt, Bakdash, Stefanucci & Proffitt, 2009).

Principles of embodied perception have been applied to the apparent steepness of locomotor challenges in the environment, such as hills and stairs, to which I will turn my attention now.

1.6 Geographical Slant Perception

Geographical slant perception refers to apparent slope of surfaces in the environment relative to the horizontal plane. This aspect of visual perception is independent from 'optical slant' – the extent of departure of a surface from the frontal plane. When exploring our environment, we are most aware of the geographical slant of surfaces because it is information from geographical slant that informs action (Gibson & Cornsweet, 1952). Specifically, geographical slant perception refers to the perception of hills and staircases. Conscious perception of geographical slant is universally overestimated such that these locomotor challenges, when viewed from their base, appear steeper than their physical incline (Proffitt et al., 1995, 2006). The same is true for looking down hills from the top, however, I will deal with the perceptual experience of looking up locomotor challenges in this chapter.

The most extensive explanation of geographical slant perception is provided by Proffitt's 'economy of action' account (Proffitt, 2006), which was recently revisited in a book chapter entitled 'perception viewed as a phenotypic expression' (Proffitt & Linkenaugar, 2013). Proffitt's model proposes that our ability to act on the environment directly influences our explicit perception of our surroundings. In the context of hill perception, the apparent steepness of such locomotor challenges will change dependent on the available resources of the perceiver. This viewpoint reflects an embodied perception of spatial layout. Some researchers, however, remain sceptical of the economy of action account, despite more than two decades of experimental evidence to support this view. An alternative account proposes that our perceived slant of large scale surfaces is more constant, and differs not due to differences in bodily ability, but optical factors such as viewing distance and frontal tendency (Durgin, Ruff & Russell, 2013; Li & Durgin, 2010).

1.6.1 *Early Research on Geographical Slant Perception*

The majority of early research into slant perception focussed on optical slant. The appreciable difference between the associated visual processing of optical slant and geographical slant was not fully appreciated until Proffitt's line of research on the topic began in the mid-1990s. Two prior studies, however, document the tendency to grossly overestimate geographical slant in explicit reports, despite the fact that optical slant is generally underestimated (Perrone & Wenderoth, 1991). Kammann (1967) reported the perceptual tendency to overestimate geographical slant, also noting that females did so more than males. Ross (1974) discussed both uphill and downhill perception of geographical slant, providing a number of anecdotal accounts of overestimation similar to those recorded by Kammann. Both studies referred only to explicit reports of perceived steepness for measurement.

1.6.2 *Dissociation between perception and action*

The perception of geographical slant provides a naturalistic example of dissociation between perception and action in line with the two-system theory of visual perception (Goodale & Milner, 1992). In the first extensive study of geographical slant perception, Proffitt, Bhalla, Gossweiler & Midgett (1995) tested over 300 students for their perception of nine rolling hills around the University of Virginia campus (2° - 33°). Participants provided three measures of perceived geographical slant from the base of each hill. These three measures continue to be the standard forms of measurement used in research on the topic. Two measures were used to tap into explicit perception; a verbal report of the apparent slant angle of the hill (verbal measure), and a manual adjustment of a pie-shaped segment of a disk device (Figure 1.6) to create a cross-section of the perceived slant angle (visual measure). A third measure allowed participants to visually match the slant of the hill using touch (haptic measure). The device Proffitt developed for this task was the ‘palm-board’ (Figure 1.6).

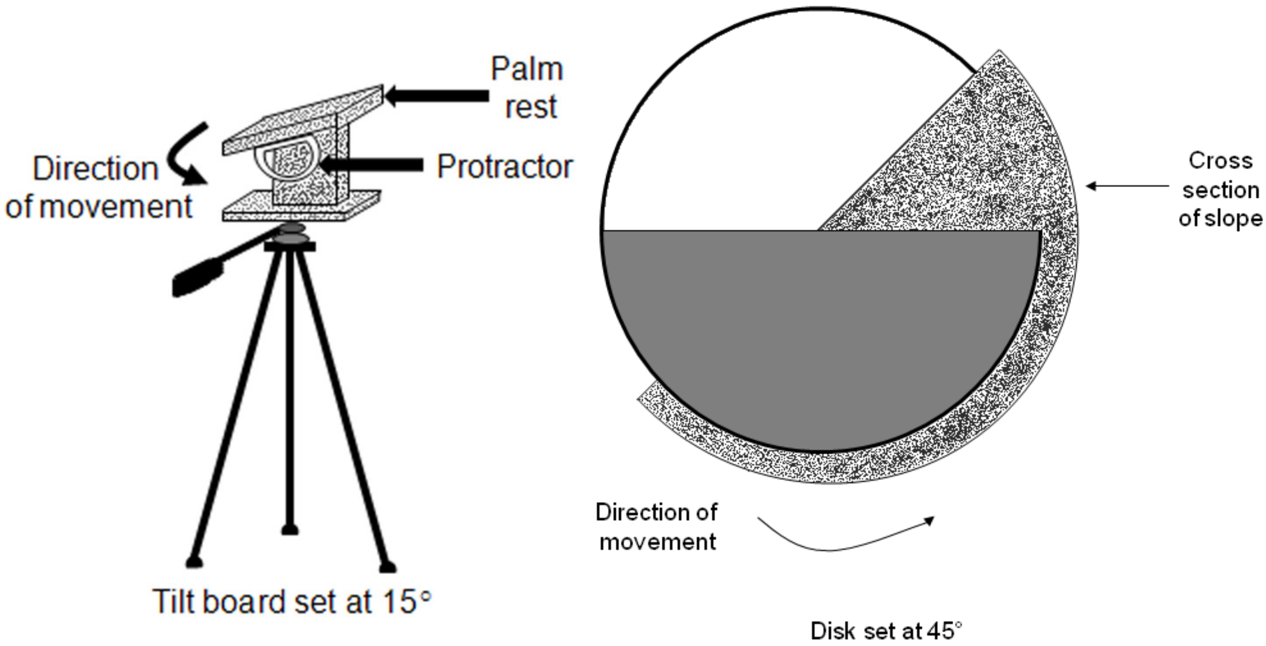

Figure 1.6. Apparatus used by Proffitt et al. (1995). The ‘palm-board’ (left), used to ‘haptically’ judge geographical slant – participants place their dominant hand on the palm rest and tilt it back until their hand feels as though it is in line with the slope of the hill. The disk device (right) used to provide ‘visual’ judgements of geographical slant.

Proffitt and colleagues’ investigation uncovered a significant difference between responses on explicit measures (verbal and visual) and an action measure (haptic). Explicit reports showed gross overestimation of perceived geographical slant such that a 10° hill was verbally reported as roughly 30°, and visually matched as roughly 25°. Haptic matches with the palm-board, however, were relatively accurate. Proffitt and colleagues (1995) argued that verbal and visual measures tapped into ventral stream perception, while the haptic measure tapped into dorsal stream perception. In line with Goodale & Milner’s model (1992), a measure associated with dorsal stream processes was most accurate. Ventral stream measures, however, appeared to be affected by some process that biased perception to make hills appear steeper. As such, Proffitt and colleagues' finding echoed the results of experiments using visual illusions as stimuli such that ventral streams measures were prone to error, but visually guided actions were not. In summary, the dissociation between, ventral stream measures of perceived geographical slant, and an action measure associated with dorsal stream processes, suggested that the locomotor challenge of slanted obstacles such as hills and staircases act as naturally occurring visually illusions.

Conscious misperception of the environment might sound like a problematic aspect of vision, however, Proffitt (1995, 2006) contends that it serves a function. By perceiving locomotor challenges as steeper than their physical incline, we are better informed of the energy consequences of any given ascent. Sensitivity to geographical slant in conscious awareness might deter perceivers from what would be an energy costly behaviour. As previously discussed, energy minimisation is the requisite of survival positive processes. Since his original study, Proffitt (2006) has since conceived that perception of geographical slant might be under evolved pressures to result in an exaggerated visual experience of steepness. Dorsal stream perception, as measured by haptic reports, remains generally accurate, for if a perceiver was to attempt a climb, they require accurate information about how to adjust one's gait to transverse the slanted surface. In summary, the visual stream that *informs* action, is manipulated by the implicit demands of energy preservation, while the visual stream that *executes* action has access to accurate information regarding incline so that when we do climb, we do so efficiently.

1.6.3 *A Psychophysical Power Law*

Further evidence for geographical slant perception being a functional adaptation of the visual system is supplied by the fact that it conforms to a psychophysical power function. Sensitivity to geographical slant stimuli is inversely related to the *intensity* of stimuli. Proffitt et al. (1995) noted that overestimation of geographical slant had a heightened sensitivity at the bottom end of the scale (closer to a flat ground plane). In reviewing his model, Proffitt (2006) points out that we are very skilled perceivers when it comes to determining whether the ground plan we are faced with is sloping upwards or downwards, even when the incline is less than 1°. We struggle, however, to distinguish the difference between two similarly steep slopes, such as two hill of 30° and 31°. Proffitt contends that this is an important aspect of geographical slant perception, because differentiating between a slope of 5° and 6° is of far more behavioural relevance than differentiating between slopes of 30° and 31°.

1.6.4 *Demographic Influences*

Explicit reports of geographical slant differ between demographic groups such that those individuals who would, on average, have less available resources for climbing provide steeper estimates of geographical slant relative to their counterparts. In most cases, these between-group differences are only observed on explicit measures.

1.6.4.1 *Sex*

Physiological differences mean that, on average, men are fitter and stronger than women (Keller, 1989; McArdle, Katch & Katch, 1981; Taylor et al., 1997). As a result, men use a lower proportion of their available resources for any given climb relative to women. In line with an embodied account, these physiological advantages are reflected by reduced overestimation of geographical slants in men relative to women. In Proffitt et al.'s (1995) initial investigation into geographical slant perception, the authors observed robust differences between the sexes such that females provided significantly steeper estimates of slant relative to males across a range of nine hills. The effect of sex has been shown to generalise to the perception of stairs. In a recent study of 269 commuters recruited in a train station, Eves, Taylor-Covill & Thorpe (submitted) showed that sex was an independent predictor of verbal and visual slant judgments for a large staircase (23.4°). Women provided reliably greater explicit estimates than men, even when other demographics such as age, height and weight were controlled for in a multivariate analysis.

1.6.4.2 *Age*

Both muscular strength and cardiovascular fitness are negatively correlated with age (Lindle et al., 1997). Decreased behavioural potential over time means that age itself is negatively correlated with the ability to physically interact with the environment. The ability to climb is particularly affected because much of the work is done around the hip region, which suffers from the additional burden of reduced flexibility with age (Shephard, 1995). As with sex, both between-group comparisons and cross-sectional investigations suggest that physiological differences between the old and young affect explicitly perceived geographical slant. Bhalla & Proffitt (1999) showed that a sample of 32 elderly participants (aged 60-87 years) provided more exaggerated verbal and visual judgments for steep hills (25° and over) relative to a group of student-aged participants. Furthermore, Eves et al. (submitted) showed that age was an independent predictor of explicit perceptions of staircase slant. When included in linear regression models, age in years was positively correlated with both verbal and visual measures of perceived slant.

1.6.4.3 *Bodyweight and Height*

Only sparse data is available on the influence of bodyweight and height on slant perception, however, when formally tested by Eves et al. (submitted) these factors appear to influence the extent of staircase overestimation in explicit perception. The authors decomposed the health metric Body Mass Index (BMI) into two separate components for height and weight before mean-centring the variables across sex. When included in linear regression models, the new variable for participant height was independently correlated with verbal estimates of staircase slant such that taller people reported the stairs as less steep. In the same model, the variable for bodyweight was correlated with verbal estimates such that heavier people reported the stairs as steeper.

Although not formally covered in Proffitt's accounts of his model (2006, 2013), these findings are consistent with the 'economy of action.' The amount of energy consumed in climbing a given hill or staircase is directly affected by the amount of dead weight an individual carries in the form of bodyfat (Weinsier et al., 2000). Consistent with this premise, Eves and colleagues (submitted) suggested that this is reflected by steeper reports of geographical slant in heavier participants. Moreover, increased height is an advantage in climbing stairs. Being taller means having longer legs and subsequently longer levers around hip and knee joints. This means that taller climbers produce smaller angles of flexion around the hip and knee joints during stair climbing, resulting in greater biomechanical efficiency, with the knock on effect of reduced energy requirements for any given climb relative to shorter individuals (Warren, 1984).

1.6.4.4 *Fitness and Health*

While not strictly a 'demographic' – fitness and health are generally stable bodily factors in the short-term. Individuals of a higher cardiovascular fitness find climbing easier than unfit participants, and will incur a smaller proportion of total energy loss for a given climb. Available data confirms the relationship between explicit perception of geographical slant and physical fitness. Cross-sectional data collected by Bhalla & Proffitt (1999) showed that objectively measured factors related to fitness were strongly correlated with verbal and visual judgements of hill slant. Further, Schnall, Zadra & Proffitt (2010) modelled several factors against perceived geographical slant, showing that participants who reported more physical exercise on a questionnaire provided less steep verbal and visual estimates for a 5.6° hill. In both studies, no relationship emerged between fitness and haptic measures of perceived slant.

In essence, Proffitt's model (2006) predicts that a fit and healthy 60 year old woman who exercises five times a week and competes in senior distance running would report hills as less steep than a 'couch potato' of a 25 year old male who has an unhealthy diet and leads a sedentary lifestyle. While demographic effects on explicit measures of perceived slant are generally robust in a large sample, Proffitt (2006) suggests that every individual has their own level of available resources that determines the extent to which they overestimate the steepness of locomotor challenges.

1.6.5 *Energetic Influences*

Differences in available resources between persons of different bodily compositions are relatively permanent, however, our individual level of available resources is subject to short-term change. Resources are boosted following an energy-rich meal or beverage, and resources are depleted after a bout of exercise. Evidence used in support for the economy of action account shows that the visual system appears to recalibrate conscious awareness of steepness in line with the body's current level of available resources. Changes to perceived geographical slant appear to take place with little delay, suggesting that knowledge of available resources and explicit perception are cognitively linked. Several factors, reviewed below, have been experimentally manipulated in previous studies, resulting in significant changes to explicit estimates of perceived slant, but not haptic measures.

1.6.5.1 *Fatigue*

In two similar studies, Proffitt et al. (1995), along with Bhalla & Proffitt (1999) showed that cardiovascular fatigue resulted in estimates of hill slant that were more exaggerated. In both experiments, participants who regularly ran to keep fit were sent on an exhausting run around their university campus before meeting an experimenter at an agreed hill. For both tame (5°) and steep (31°) hills, verbal and visual estimates of perceived geographical slant increased significantly after the run, however, no significant changes were observed for haptic estimates. Bhalla & Proffitt observed that the sensitivity to change was double for the shallower hill, a result that provides further evidence for perceived geographical slant acting as a power law. In both experiments, the effect of fatigue had a stronger effect on the 5° hill, increasing explicit estimates by a combined average of 40% relative to a 20% increase on the 31° hill.

1.6.5.2 *Encumberment*

A further experiment from Bhalla & Proffitt (1999) suggests that the perceiver does not have to be fatigued in order for the visual system to pick up increased costs of climbing. In the 'backpack experiment,' 40 members of a 130 person sample wore a heavy rucksack containing gym weights totalling 16.7-20.7% of their bodyweight. Results showed that, relative to unencumbered individuals, participants wearing the heavy backpack provided steeper verbal and visual judgements of hill slant. The authors suggested that perceivers *sensed* the increased costs of climbing with the heavy backpack on, which led to a more exaggerated conscious awareness of hill steepness. As with the fatigue manipulation, there was no effect on the haptic measure, and estimates for the 5° hill increased by a larger proportion than for the 31° hill.

1.6.5.3 *Blood Glucose*

Glucose is the primary source of energy for a quick intense bout of exercise such as climbing a hill or staircase. As such, it is an ideal candidate to test the affect of short-term physiological changes in energy resources on perception of geographical slant. Schnall, Zadra & Proffitt (2010) investigated the role of circulating blood glucose on geographical slant perception in two experiments. In their first study, Schnall and colleagues had participants fast for three hours prior to arrival before providing with them with either a sugary drink (boosted condition) or a drink containing artificial sweetener (depleted condition). Glucose was then further depleted via a demanding cognitive task. Follow-up estimates of geographical slant for a 29° hill showed participants who had consumed the sugary drink provided shallower verbal and visual estimates of slant relative to those who had consumed the drink that was absent of energetic replenishment. Those participants whose resources had been boosted by the sugar intake demonstrated decreased explicit awareness of hill steepness. In a follow-up experiment, Schnall and colleagues replicated this finding with direct measurements of circulating blood glucose through blood sampling after a similar manipulation. As with previous manipulation, changes to available energy resources did not affect responses on a haptic measure.

1.6.6 *Psychosocial Influences*

Explicit reports of geographical slant are not only affected by physical characteristics that influence our energetic state such as fatigue and available energy stores. Affective states can both empower or disempower individuals into perceiving the world as a less or more challenging environment. Several additional cognitive factors have been documented that appear to influence conscious awareness of geographical slant.

1.6.6.1 *'Bioenergetics'*

In Schnall et al.'s (2010) second experiment of glucose and geographical slant, controlling for individual differences in 'bioenergetics' improved the accuracy of determining the effect of their blood glucose manipulation. Bioenergetic state was assessed via a battery of questionnaires designed to test fatigue (physical and cognitive), sleep quality, stress, mood, exercise frequency and nutrition. Factor analyses determined four factors that all correlated with verbal and visual estimates of hill slant in the expected direction, but no relationship with haptic estimates. Results revealed evidence for several previously undocumented factors that can influence the extent to which geographical slant is overestimated, namely; mood, sleep quality, hours since waking, level of cognitive fatigue and perceived stress.

The effect of mood has since been formally tested in a manipulation based study. Across two experiments, Riener et al. (2011) showed that positive mood led to shallower estimates of geographical slant, and that negative mood led to steeper estimates of geographical slant. The authors manipulated the emotional state of participants by playing either happy or sad music (experiment 1) or having them recall a positive or negative experience (experiment 2) before making hill judgements. The authors drew on previous work by Galliot et al. (2007) that suggests being in a negative mood required more glucose than being in a positive one. Hence, they suggest that participants in a sad condition were more depleted of resources, and subsequently perceived the hill as requiring more of their relative energy stores than those participants in the happy condition resulting in steeper explicit reports of geographical slant.

1.6.6.2 *Social Support*

Social support is well-documented as a powerful psychosocial resource. The presence of others acts as a barrier to ill health, reducing the risk of many diseases (Uchino, 2009), and can also act as a buffer against the effects of mental health (Cohen & Wills, 1985). Critically, social support can also help to control increased cardiovascular reactivity to stress brought on by environmental threats (Kamarck, Manuck & Jennings, 1990). In the context of slant perception, steep hills afford a threat to a perceiver because climbing might significantly reduce their energy resources, and attempting to go down a hill might result in a fall leading to injury. Consistent with this premise, evidence suggests that having a friend by one's side makes hills appear less steep. Schnall, Harber, Stefanucci & Proffitt (2008) used a quasi-experimental design whereby participants were recruited while passing by a hill and assigned to either a 'high' social support group if they were accompanied by someone on their walk, or a 'low' social support group if they were walking alone. Those who judged hill slant with a companion by their side provided shallower verbal and visual hill estimates relative to those who judged the hill alone. Furthermore, the quality of the relationship between the perceiver and their partner mediated the effect of social support such that participants who had known their companion longer and had a stronger connection with them perceived the hill as even less steep.

In the context of action, having a friend present while ascending or descending a hill might act as a sort of ‘safety net.’ The presence of a trusted person ensures that should one fail to complete the associated action of hill climbing or descent, there is someone there to provide assistance. As such, the hill presents less of a threat, and is perceived as less steep. Alternatively, the effect of social support on perceived slant might be linked to available resources. If locomotor challenges in the environment such as hills and stairs trigger a type of stress response, this would incur a loss of glucose that might be used to transverse the environment, since social support buffers the extent of stress responses, having a close friend by one’s side might help preserve available energy resources, making more glucose available for locomotion, with the knock-on effect of hills appear less steep.

1.6.6.3 *Motivational State*

Cognitive dissonance, the psychological discomfort of having conflicting cognitions, has also been linked to perception of geographical slant. Balcetis & Dunning (2007) manipulated participants’ motivational state by making them feel as though they have no choice to complete a socially humiliating task (low-choice condition), or had actually chosen to complete the task (high-choice condition). Those in the high-choice condition were more likely to seek consonance between expectations and the humiliating task itself. This would lead to maintenance of psychosocial resources relative to someone who was struggling with the partaking in the task. In line with resource consumption being linked with perceived geographical slant, those participants who felt as though they had less choice, and were more likely to be having their resources consumed by cognitive dissonance, provided steeper visual matching estimates of hill slant than participants in the high-choice condition.

1.6.6.4 *Psychological Burdens*

Harbouring secrets consumes psychological resources and can negatively influence our physical health (Pennebaker, 1989). Consistent with reduced resources leading to more exaggerated perceptions of slant, Slepian, Masicampo, Toosi & Nalini (2012) showed across a series of experiments that participants who recalled an important secret, reported preoccupation with an important secret, or were actively suppressing an important secret, all reported hills as steeper. The authors suggested that psychological burdens weigh people down in the same way as the physical burden of a backpack does (Bhalla & Proffitt, 1999), and might affect perception by the same cognitive process.

1.6.6.5 *Priming*

Judgments of geographical slant can also be manipulated by semantic priming (Chambon, 2009). Evidence suggests that by *embodying* a less physically able person our visual experience of hill steepness increases. Chambon (2009) showed that when primed with words associated with elderly people such as ‘retired,’ ‘wisdom,’ or ‘solitude,’ participants verbally reported a set of sloped pathways and a hill as steeper than participants who were not primed.

1.6.7 *Comparisons with Stair Climbing Research*

The similarities between the behavioural tendencies of pedestrians approaching stair climbing points-of-choice and demographic differences in geographical slant perception make it plausible the two are linked. Indeed, in a recent review of stair climbing behaviour literature, Eves (2013) pointed out that the economy of action account is the only available explanation for why certain individuals are more likely to avoid stair climbing than others.

As reviewed earlier (section 4), Eves (2013) presented data from 43 observational studies showing that females avoid stairs more than men, the elderly more than the young, the overweight more than those of a healthy weight, and those carrying bags more than those free of additional loads. These data are consistent with that collected in studies of geographical slant perception. While this cannot prove that perceived steepness drives the choice to climb stairs or avoid them, the fact that those demographic effects so rarely go in the opposite direction to what Proffitt's model would predict (only twice in 130 comparisons) makes the potential for a linkage between perception and locomotor behaviour clear (Eves, 2013).

1.6.8 *Alternative accounts of geographical slant perception research findings*

Proffitt's account is not without contest. In recent years, the evidence used to support the economy of action account has come under intense scrutiny.

1.6.8.1 *Issues with 'action measures'*

Proffitt's group have always contended that palm-board estimates represent an action measure such that the tilting of the board to match geographical slant uses dorsal stream processes (Proffitt, 1995, 2006). Researchers unaffiliated with Proffitt's group have also reported generally accurate estimates when using similar measures to the palm-board. For example, participants in a series of experiments by Feresin & Agostini (2007) adjusted a paddle board with their hand to estimate the slant of urban roads. In both the natural environment and a laboratory setting, judgements did not differ from the physical slant of the roads when stimuli were viewed from less than 4 meters away. Furthermore, in a study that predates Proffitt's work on geographical slant, Kinsella-Shaw, Shaw & Turvey (1992) showed that participants were generally accurate at judging the slant of walkable surfaces when adjusting an unseen foot ramp to match the slope.

A series of studies by Durgin, Hajnal, Li, Tonge & Stigliani (2010), however, concluded that palm-board measures were "*biased and variable due to poorly calibrated proprioception of wrist flexion*." Durgin (2010) argues that adjusting a palm-board makes use of only one degree of freedom, the wrist joint, which has a restricted range of motion. They suggest that the resulting judgements of slant made with a palm-board are actually underestimates of proprioception, and "*accidently accurate.*" The implication of Durgin and colleagues' work is that one must take a second look at geographical slant perception as representing dissociation between perception and action. If palm-boards are not action measures, then no reliable test for dissociation can be been made.

In reply, Proffitt & Zadra (2010) suggest that the results of Durgin's investigations into haptic perception of slant do not generalise to their work with hills. It is of note, that only one of Durgin et al.'s (2010) experiments used a real hill. Furthermore, Durgin later admits that the palm-board used in two of the five experiments in his 2010 paper, including the only study that used a real hill as stimulus, was *"problematic"* (Durgin, Hajnal, Li, Tonge & Stigliani, 2011).

While there are problems with Durgin and colleagues' argument against the use of palm-boards, it should be noted that palm-boards do have several limitations as 'action measures.' When matching slant by adjusting a tilt board with the hand, the movement is away from the hill, not towards it. Furthermore, the palm-board's design means the hand is not masked from view when a participant adjusts the tilt-board to match slant. Participants can, if they wanted to, 'peek' at their hand while adjusting the tilt-board. Visual feedback on hand position distracts from the measure being strictly be dorsal stream.

1.6.8.2 *Experimental demand characteristics*

First discussed by Orne (1962), demand characteristics refer to when participants in psychology experiments form an expectancy about the hypothesised outcomes of the study in which they are partaking that influences their responses. Nicholas & Maner (2008) suggest that in many studies, the 'good-subject effect' takes place whereby participants provide responses that comply with the perceived demands of the study.

In a critique of Proffitt and colleagues' work, Durgin, Baird, Greenburg, Russell, Shaughness & Waymouth (2009) presented evidence that suggested the effect of the manipulation used in Bhalla & Proffitt's 'backpack experiment' might be an artefact of experimental design. Durgin suggested that participants could have *deduced* the intention of the manipulation and provided more elevated explicit estimates of geographical slant in line with perceived experimental demands. When Durgin et al. (2009) partially replicated the backpack experiment, they found that when a cover story was given for the backpack that slant estimates were not more exaggerated than when participants were unencumbered. The authors suggested that experimental demands might be used to explain the results of several previous studies similar to the backpack experiment that have been conducted by Proffitt and colleagues to provide evidence for his model.

Stronger evidence for physiological resources affecting explicit perception of geographical slant was presented by Schnall et al. (2010) not long after Durgin and colleagues provided their alternate account of the phenomenon. Nonetheless, a further explanation related to effects of experimental demands surfaced once again that brought into question Schnall and colleagues' findings. Durgin, Klein, Spiegel, Strawser, & Williams (2012) suggested that because participants in Schnall's study wore backpacks, this acted an as uncontrolled demand characteristic. Glucose regulates self-control (Galliot et al., 2007), hence, Durgin argues that it is possible participants who had received the sugary drink were better able to *resist* the experimental demands of the backpack than those who received the drink containing artificial sweetener. Durgin and colleagues (2012) presented a series of experiments the results of which suggested that beliefs about why they were asked to ingest a drink as part of the study mediated the effect of a glucose manipulation. In direct similarity, a study by Shaffer, McManama, Swank & Durgin (2013) showed that participants who reported more susceptibility to experimental demands in a post-experimental questionnaire were more likely to respond with reduced explicit estimates of geographical slant following a glucose manipulation.

The new perspectives offered by Durgin, Shaffer, and others has sparked a lively debate on the subject of embodied perception of geographical slant (e.g., Firestone, 2013), however, in a number of the studies, methodological flaws prevent the findings generalising to Proffitt's model. As Proffitt & Zadra (2010) point out, Durgin and colleagues rarely use climbable surfaces in their studies, and sometimes use surfaces that do not afford a significant enough climb to the relevant to the economy of action. For example, Durgin et al. (2009) used a small ramp lodged against a door to measure perceived geographical slant.

Crucially, no other account provides an explanation for one of the most robust effects of all, that of sex. The fact that females overestimate geographical slant more than males appears to have been ignored by those who oppose Proffitt's view. If results of experiments into geographical slant perception are driven by experimental demands and not differences in perception, then why would women believe they are *expected* to report hills and stairs as steeper?

1.7 Purpose of the Current Thesis

The outset of this project coincided with an emergence of some aggressive critiques opposing Proffitt's model of geographical slant perception. Consequently, this thesis first set out to test fundamentals of the 'economy of action' account using new approaches that might confirm or deny its efficacy. Only when Proffitt's model could be confirmed could work begin on how this model might be used to explain physical activity behaviour in the built environment.

Chapters two and three focus on 'haptic' perception of geographical slant. Recent reports suggest that the palm-board measure developed by Proffitt to measure 'haptic' perception is insufficient as an 'action measure' of geographical slant (Durgin et al., 2010). In order to effectively test for dissociations between explicit perception and action measures, the accuracy of 'haptic' perception in this context needed to be confirmed. In chapter one, a large scale study used a range of hills and staircases to test a newly developed measure of perceived geographical slant, the Palm-Controlled Inclinometer (PCI), which improves on certain aspects of the palm-board, some of which were brought into question by Durgin and colleagues (2010). Results suggest that the PCI and palm-board tap into the same perceptual process that is reflective of a much more accurate perception of geographical slant than explicit measures. This study was subject to a reply (Durgin, 2013). Chapter three contains my response to Professor Durgin, the aim of the paper being to provide an explanation as to why Proffitt and Durgin's groups come to such discrepant conclusions over 'haptic' perception of geographical slant. More detailed discussion of haptic perception is provided to explain why these 'action measures' could be linked to a perceptual process with access to more accurate information about the physical layout of the environment relative to explicit measures of geographical slant perception.

In chapter four, I test how fundamentals of Proffitt's model generalise to a laboratory environment that might allow future researchers to have tighter controls over the physical condition of participants. Most previous research into geographical slant perception has been conducted outside, where physiological measurements are limited. The mechanisms that drive the perceptual bias of geographical slant still remain conceptual, so moving from the environment into the laboratory marks a step towards uncovering the underlying processes behind embodied perception. Two experiments are presented that show the perceptual tendencies of geographical slant perception can be replicated in a laboratory environment using life-sized images of locomotor challenges as stimuli.

While chapter four showed an effect of resources on perception, researchers who oppose Proffitt's model would argue that results might be put down to influences of experimental demands (Durgin et al., 2009; 2012). The purpose of chapter five was to develop an experimental design that minimised the potential for experimental demands while testing the affect of energetic resources on perception of geographical slant. Using a quasi-experimental design that masked the purpose of the study, a novel 'post-choice paradigm' was employed to test the link between available energy resources and perceived geographical slant in a field setting. Participants unknowingly chose their own experimental grouping by selecting from a set of food or drink items either before or after providing judgements of geographical slant for a large staircase. Across two studies, those participants opting for items more likely to boost their resources provided steeper verbal and visual estimates of slant.

Chapters six and seven focus on the possible link between perceived geographical slant and stair climbing behaviour in the built environment. Chapter six presents a correlational study where behaviour was measured by participants recalling past stair climbing in a train station setting. Commuters that reported more stair climbing at the site verbally reported a staircase as shallower than those revealing a higher likelihood of taking an adjacent escalator. Although the data from chapter six supported the link between perception and stair climbing behaviour, it could not confirm causality. Hence, the purpose of chapter seven was to measure objective physical activity behaviour alongside perception of geographical slant at a stair climbing point-of-choice. A quasi-experimental study is used where pedestrians are recruited in the built environment after they have made a choice to avoid or climb stairs, but before the behaviour had been executed. Those avoiding stair climbing showed a more exaggerated perception of staircase steepness, independent of demographic differences, providing direct behavioural evidence for the economy of action account.

1.8 References

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CHAPTER 2

In my first experimental chapter I present a work that stemmed from what was initially a simple validation study of a new 'haptic' device to be used in throughout this thesis - the Palm-Controlled Inclinometer (PCI). Shortly after this work was completed, a heated debate developed within the field of geographical slant perception concerning the efficacy of 'haptic' measures of geographical slant perception that Proffitt uses to demonstrate dissociation between perception and action in the context of geographical slant. As such, this study was expanded into a formal publication with an added experiment to address the claims of those opposing Proffitt's viewpoint.

PAPER 1

THE ACCURACY OF ‘HAPTICALLY’ MEASURED

GEOGRAPHICAL SLANT PERCEPTION

Taylor-Covill, G. A. H. & Eves, F. F. (2013). *Acta Psychologica*

2.0 The accuracy of 'haptically measured geographical slant perception

2.1 Abstract

In two recent issues of Acta, the widely accepted view of Proffitt (2006), that 'haptic' measures of perceived geographical slant are generally accurate, and dissociated from explicit overestimates, came under intense scrutiny (Durgin, 2010, 2011). Durgin and colleagues challenge to this account centred on the claim that Proffitt's 'haptic' measure of geographical slant, the palm-board, may be accidently accurate due to restricted movements available at the wrist. Two experiments reported here compare the accuracy of Proffitt's palm-board with an alternative measure of geographical slant perception, the Palm-Controlled Inclinometer (PCI), which allows participants to use wrist, elbow and shoulder movements to match slant with their hand. Participants (n=320) made slant judgments using both measures, across five hills and five staircases with 32 participants for each stimulus angle (4.5° - 31°). Results for the palm-board replicated those of Proffitt and co-workers, overestimation at shallow angles (≤14°), contrasted with underestimation at steeper angles (≥23°), whereas estimates made using the PCI had a greater degree of accuracy for steeper slopes. A follow-up experiment tested the accuracy of the palm-board and PCI for surfaces in near space to repeat the design of Durgin et al (2010, experiment 1). Participants (n=20) used the palm-board and PCI to judge the angle of slanted blocks (25°, 30°). As with traversable slopes, PCI judgements did not differ from the actual angle of the blocks whereas the palm-board measure underestimated. 'Haptic' measures of geographical slant perception can be accurate for relatively steep slopes, in both near and far space.

2.2 Introduction

When standing at the base of a hill, our visual perception of its steepness is exaggerated. The first formal exploration of the apparent steepness of hills, termed geographical slant perception, concluded that while our explicit awareness of hill slant is prone to overestimation, when using a 'haptic' measure, we are more accurate at judging a hill's incline (Proffitt, Bhalla, Gossweiler, & Midgett, 1995). The measure developed to test 'haptic' perception of hill slant was the palm-board (Fig. 1). Participants place their palm on the board and, without looking at their hand, tilt back the board to match the slant of the hill. This device is still actively being used in geographical slant research with no apparent changes to its design (e.g. Riener, Stefanucci, Proffitt, & Clore, 2011). Throughout this paper, the descriptor that Proffitt et al. (1995) used for these palm-board measures, 'haptic', is retained for comparability with previous studies despite its more common connotation with touch.

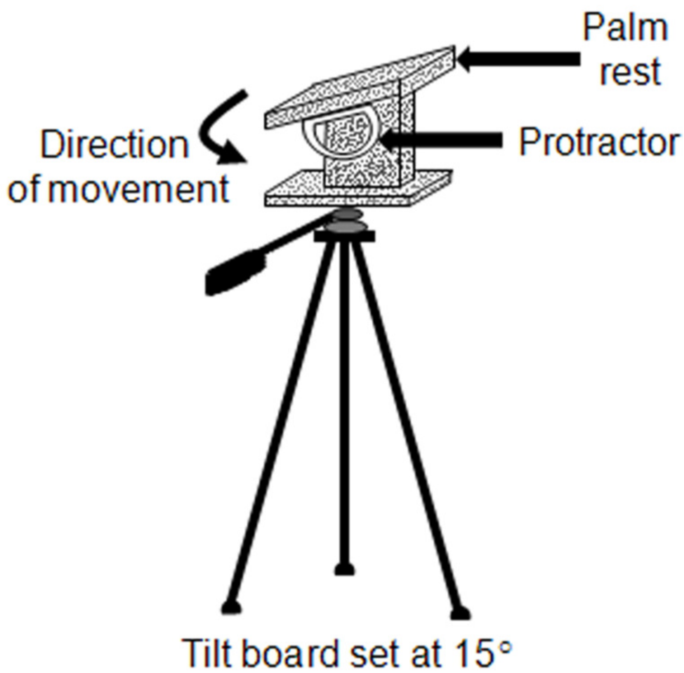

Figure 2.1. Depiction of Proffitt's Palm-Board measure traced from Proffitt et al. (1995)

Since Proffitt and co-workers' initial research into geographical slant perception, subsequent studies which have used the palm-board consistently suggest that it provides a more accurate measure of the actual slant of real-world stimuli than measures Proffitt links to explicit awareness, such as verbal reports and visual matching. Furthermore, studies have shown that 'haptic' estimates with the palm-board are unaffected by changes in behavioural potential. For example, when participants were encumbered by a heavy backpack, or sent on exhausting runs, their verbal reports and visually matched estimates of hill slant increased (Bhalla & Proffitt, 1999). Palm-board estimates on the other hand, showed no effects of either manipulation. Subsequent studies reveal the same pattern of results. While verbal and visual judgements respond to manipulations of energy resources (Schnall, Zadra, & Proffitt, 2010), psychosocial resources (Schnall, Harber, Stefanucci, & Proffitt, 2008), fear (Stefanucci, Proffitt, Clore, & Parekh, 2008), and mood (Riener, et al., 2011), judgements made using the palm-board are unaltered, suggesting a more stable process is used for 'haptic' judgement of geographical slant.

Researchers unaffiliated with Proffitt's group have also reported generally accurate estimates when using similar measures to the palm-board. For example, participants in a series of experiments by Feresin & Agostini (2007) adjusted a paddle board with their hand to estimate the slant of urban roads. In both the natural environment and a laboratory setting, judgements did not differ from the physical slant of the roads when stimuli were viewed from less than 4 meters away. Furthermore, in a study that predates Proffitt's work on geographical slant, Kinsella-Shaw, Shaw & Turvey (1992) showed that participants were generally accurate at judging the slant of walkable surfaces when adjusting an unseen foot ramp to match the slope.

What had not been brought into question until recently was Proffitt's suggestion that using a palm-board to match a hill's slope was a relatively accurate, visually guided motor action. A series of experiments presented by Durgin, Hajnal, Li, Tonge, & Stigliani (2010) concluded that Proffitt's palm-board measure was "*biased and variable due to poorly calibrated proprioception of wrist flexion*" (p.182). Durgin et al. (2010) argue that adjusting a palm-board makes use of only one degree of freedom, the wrist joint, which has a restricted range of motion. They suggest that the resulting judgements of slant made with a palm-board are actually underestimates of proprioception, and "*accidently accurate*" (p.185, Durgin et al., 2010). In their first experiment, Durgin et al.'s participants (N=25) made adjustments with a free-hand or a palm-board to match a slanted wooden block (30°) positioned on a table in front them. Results showed that participants could reproduce the block's incline with a free-hand reasonably accurately (32.7°), but reliably underestimated when using the palm-board (19.4°). In their second experiment, Durgin et al. (2010) used a real hill (24.5° when looking straight ahead) as the stimulus, measuring verbal reports in degrees, matching with a free-hand, and 'haptic' matching using a palm-board. Verbal reports and free-hand matching estimates reliably overestimated the actual slant of the hill (+19.8° and +11.6° respectively), while those made with a palm-board reliably underestimated the hill's incline (-6.4°). Durgin et al. (2010) argued that if free-hand matching, with unrestricted proprioceptive cues, was subject to overestimation, then so should 'haptic' matching using the palm-board. They argued that palm-boards simply did not allow enough range of movement in order to reveal this overestimation. In reply, Proffitt & Zadra (2011) argued that the results with wooden blocks do not generalise to studies on geographical slant where the surface affords climbing, and questioned the accuracy of the palm-board measures of Durgin and colleagues.

While Proffitt's (2006) summary of his model of geographical slant perception suggests that 'haptic' judgements should not differ from the actual slant of the stimulus, the original normative data from Proffitt et al (1995) reveal a different picture (see also Proffitt and Zadra, 2011). The 'haptic' measures differed from the actual slant in three out of four studies, though *"the magnitudes of these differences were quite small when compared with the verbal and visual measures"* (page 425; Proffitt et al., 1995). When judging real hills from their base with the palm-board, participants overestimated for angles ≤10°, were accurate for the 21° and 31° hills and underestimated the slant of the steepest hill tested, namely 34°. In the studies presented by Durgin et al. (2010), however, average palm-board judgements reliably underestimated the stimuli throughout. This discrepancy led Proffitt & Zadra (2011) to raise concerns about the apparatus used in Durgin et al's experiments, suggesting the palm-board might have been more difficult to adjust than Proffitt and co-workers' palm-boards.

Given the nature of the argument between Proffitt and Durgin's groups, new 'haptic' data for the study of geographical slant perception should be informative. Coincidently, during the period over which this debate was taking place, a new measure of geographical slant perception was being developed by an independent research group. This device, the 'Palm-Controlled Inclinometer' (PCI), forms a key measure in a programme of research investigating pedestrians' perceptions of the real-world stimuli of public access staircases, which are typically between 20° and 30° in slant angle. Like Durgin and co-workers, we were concerned that restriction of movement around the wrist joint may influence palm-board estimates for the relatively steep stimuli characteristic of stairs in the built environment. The PCI was designed to allow participants freedom of movement around the wrist, elbow and shoulder joints when judging slopes.

In this report, we first present results of a methodological study which compared estimates of the PCI to a replica of Proffitt's palm-board measure across a range of sloped real-world stimuli. The first study tested whether comparable estimates were obtained with both measures in the field. Further, in a follow-up experiment we replicate Durgin et al.'s (2010) experiment 1 for blocks in near space but replace their free-hand measure with the PCI.

2.3 Experiment 1

2.3.1 *Methods*

To compare estimates of geographical slant between the PCI and palm-board, we used a within-subject comparison whereby participants judged the slant of a real hill or staircase on each of the two measures in a counterbalanced order.

2.3.1.1 *Participants*

Members of the University of Birmingham community (N=320, M= 23.22 years, SD= 7.06 years) were recruited "to help calibrate some equipment" as they passed by the experimenter at a given hill or staircase. Measurement order and participant gender remained balanced throughout, with 32 participants being tested on each slope.

2.3.1.2 *Apparatus*

2.3.1.2.1 *Palm-Controlled Inclinometer (PCI)*

The PCI, depicted in Fig. 2, is a new measure of geographical slant perception, designed with particularly steep slope stimuli in mind. To judge slant with the PCI, participants place their hand on a plate that forms the base of an underslung pendulum and push it forward until they feel as though their palm is in line with the slope of the stimulus in front of them. This action of pushing the pendulum forward makes use of muscles around the wrist, elbow and shoulder joints simultaneously.

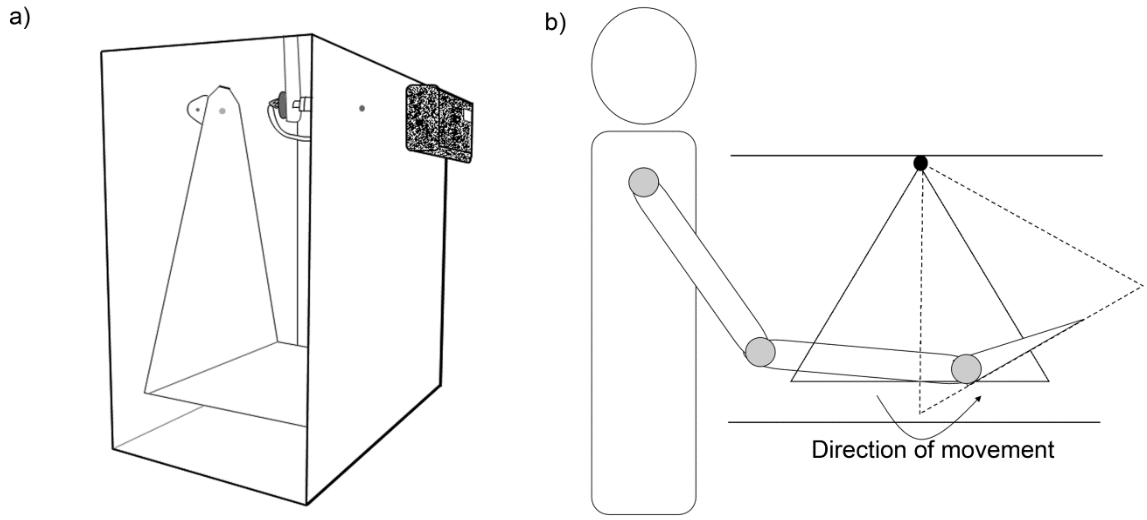

Figure 2.2. a) Schematic of the Palm-Controlled Inclinometer (PCI) showing it's measurement system incorporation. b) A demonstration of how a participant uses the PCI.

The angle to which bottom plate of the pendulum is set is measured electronically using a linear potentiometer attached to the pivot of the pendulum. As the pendulum swings, the attached potentiometer turns. A regulated voltage is applied across the potentiometer and the voltage present on the wiper of the potentiometer is zeroed and amplified. The gain of the amplifier is calibrated to report inclination in degrees to one decimal place on an LCD voltmeter attached to the side of the apparatus, outside the view of participants. The PCI has a maximum range of motion of 63°. Due to the use of an underslung pendulum the plate returns to the horizontal when the hand is removed. Full dimensions of the box and swing components of the PCI can be found in supplementary materials.

2.3.1.2.2 *Palm-Board*

The palm-board used in the current study, depicted in Fig. 3, was designed to replicate the measure used in Proffitt's studies. Rather than using a protractor to measure angle, our palm-board used an electronic measurement system similar to that of the PCI. The potentiometer was integrated into the axle at the base of the palm-board, recording palm angle in the same way as the PCI. Before each trial, the palm-board was zeroed to the horizontal using a spirit level.

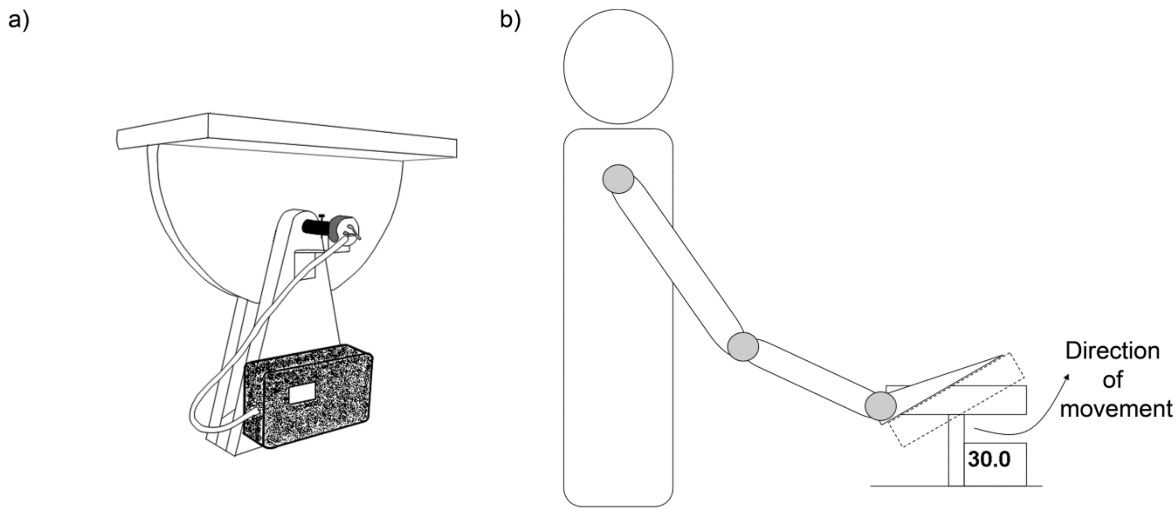

Figure 2.3 a) Schematic of the palm-board designed for the current study. The design is a replica of Proffitt's original measure but includes an electronic measurement device giving the output of board angle on an LCD display. b) A demonstration of how a participant uses the palm-board.

2.3.1.4 *Stimuli*

All stimuli were climbable surfaces which ascended over two meters high. A total of ten slopes were used; five hills (4.5°, 9°, 12°, 20° and 27°) and five staircases (14°, 19°, 23°, 26° and 31°). A range of inclinations were included in order to compare the gain of the two measures. Both hills and staircases were included to determine whether perception was influenced by the type of stimulus. All judgements were made from the base of the slopes.

2.3.1.5 *Procedure*

All participants provided judgements of slant with both the PCI and the palm-board. To begin, the experimenter adjusted the height of the device so that it was slightly above waist level of the participant in order to allow for as much freedom of movement around the arm as possible. The participant would then be instructed to either 'push the plate forward until it feels as though your palm is in line with the slope of the hill/staircase' when adjusting the PCI, or 'tilt the board back, without looking at your hand, until it feels like your palm is in line with the slope of the hill/staircase,' when adjusting the palm-board. The phrase 'without looking at your hand' was included as the hand is potentially in view when adjusting the palm-board. The participant would be prompted to 'let me know when it feels like it's in place' as they begun making their adjustments. Once the participant gave a signal that they were happy with their estimate, a reading was taken from the LCD display on the side of the apparatus. The participant was then moved to the next piece of apparatus.

After making both judgements, participants were asked to fill in their demographic information and read through an information sheet before giving consent for their data to be used in the study. Before being debriefed, participants were asked if they had ever seen either device before. None of them reported any knowledge of either apparatus.

2.3.2 *Results*

2.3.2.1 *Accuracy*

Preliminary inspection of boxplot data for each measure across the ten slopes revealed a total of 18 outliers. After exclusion of these participants, a total of 302 participants (152 male) were included in the analysis. In order to analyse the accuracy of slant judgements, the actual angle of the hill or staircase being judged was subtracted from palm-board and PCI estimates. Mean errors and 95% Confidence Intervals (CIs) for the palm-board and PCI relative to the actual slant angles of the ten stimuli are summarised in Table 1. Inspection of the table and CIs suggests both measures tended to overestimate for relatively shallow slopes (14°≤). For steeper slopes (≥23°), however, palm-board estimates reliably undershot the actual angle of the slopes, while PCI estimates were more accurate.

2.3.2.2 *Variability*

Table 1 also contains the coefficients of variation (CoVs) for the PCI and palm-board across the ten slopes. These were calculated by the same process described by Durgin et al. (2010), with outliers included, to assess the normalised variance of each measure. On average, the variability of the PCI (0.321) did not differ from that of the palm-board (0.318). When these results are compared to those of Durgin et al (2010, experiment 1), it is of note that the PCI, and our palm-board measure, displayed less variability than Durgin and co-workers' palm-board measure (0.756).

Table 2.1. A summary of mean perceptual errors for the PCI and palm-board from physical angle of the hills and staircases, and Coefficients of Variation (CoV) for each measure on each slope in experiment 1.

		PCI Errors			Palm-board Errors	
Slope	Mean Difference	95% CIs	CoV	Mean Difference	95% CIs	CoV
1* (4.5°)	3.19	2.00 - 4.39	0.451	2.22	1.28 - 3.16	0.401
2* (9°)	2.08	0.44 - 3.73	0.496	1.81	0.46 - 3.15	0.433
3* (12°)	2.01	0.34 - 3.69	0.338	0.53	-0.83 - 1.88	0.379
1† (14°)	2.58	1.31 - 3.84	0.300	2.05	0.12 - 3.98	0.391
2† (19°)	0.30	-1.16 - 1.77	0.246	-0.78	-2.10 - 0.55	0.226
4* (20°)	1.08	-0.18 - 2.33	0.243	-0.32	-2.02 - 1.37	0.311
3† (23°)	-0.19	-2.36 - 1.99	0.271	-2.26	-4.11 - -0.42	0.252
4† (26°)	-0.81	-3.62 - 2.00	0.371	-3.28	-5.67 - -0.88	0.305
5* (27°)	-0.73	-2.56 - 2.03	0.300	-2.66	-4.39 - -0.91	0.244
5† (31°)	-0.13	-2.45 - 2.19	0.231	-4.52	-6.61 - -2.43	0.235

*hills, †staircases. CIs = Confidence Intervals. CoV=Coefficient of Variation (outliers included).

2.3.2.3 *Analysis of Variance*

Repeated measures analyses employed four between-subject factors; Stimulus (Staircase, Hill), Slope Steepness (coded from 1-5 as in Table 1), Order (PCI first, Palm-board first) and Sex, along with a single within-subject factor of Measure (PCI and Palm-board).

The ANOVA contained a main effect of Measure ($F(1, 262) = 44.41$, $p < .001$), a main effect of Slope Steepness, $F(4, 262) = 8.03$, $p < .001$, and a significant interaction between the two, $F(4, 262) = 3.87$, $p < .01$, but no further interactions with other factors. Average palm-board and PCI estimates for each of the ten slopes, plotted against the actual inclines of the stimuli, are presented in Fig. 4. As can be seen, the difference between the two measures becomes greater as the actual steepness of the slope increases.

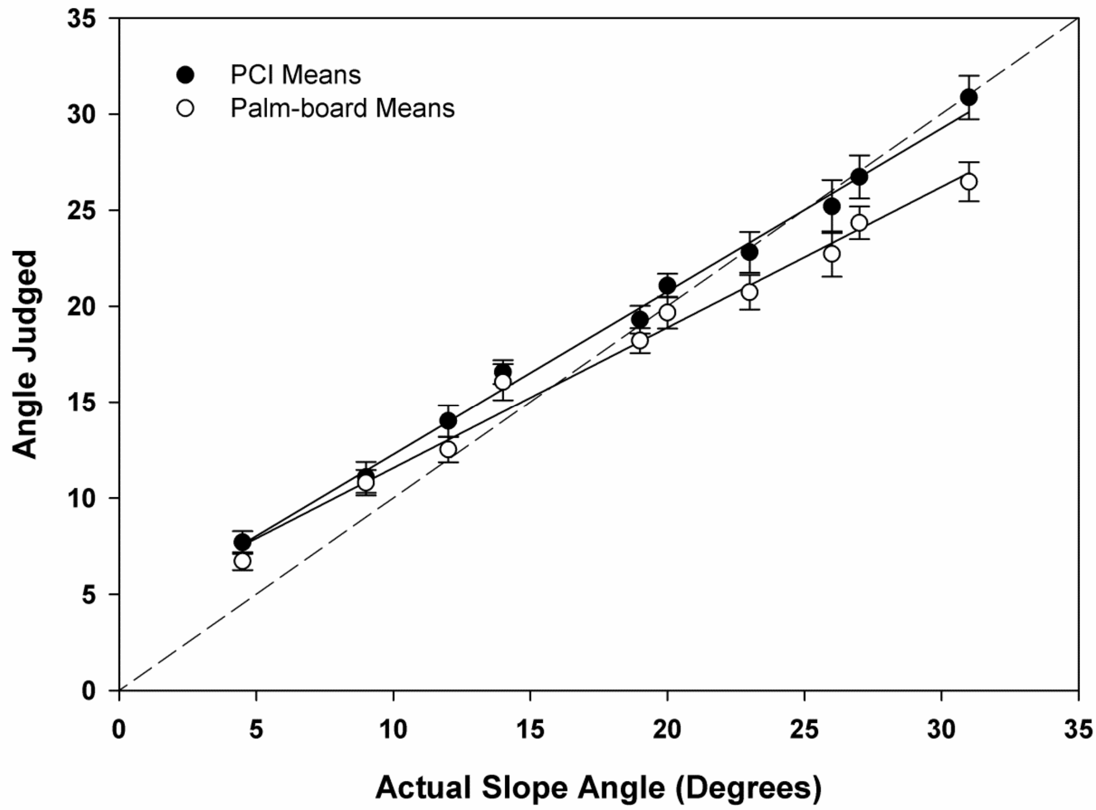

Figure 2.4. Mean slant judgements using the PCI and palm-board as a function of actual slope angle. Error bars represent +1 standard error.

The ANOVA contained a further main effect of Stimulus, $F(1, 262) = 14.27$, $p < .001$. As overestimations occur on less steep slopes for both measures, this effect of stimulus reflects the difference in the average slant of the two types of stimulus. On average staircases (22.6°) were steeper than hills (13.7°). Crucially, this effect did not interact with any other factors. In addition, a main effect of Order $F(1, 262) = 4.99$, $p < .05$, was present. This reflects the fact that, overall, errors were positive when the PCI was adjusted first (mean error= +1.28°, SE=0.57), and negative when the PCI was adjusted second (mean error= -0.39°, SE=0.58). Finally, an interaction between Measure and Sex was present ($F(1, 262) = 5.97$, $p < .05$). Follow-up paired sample t-tests revealed that PCI estimates were significantly higher than those made with the palm-board regardless of Sex, but that the magnitude of the difference was higher for females, (+2.34°, 95% CI=1.62-3.06, $t_{149} = 6.41$, $p < .001$) than for males (+1.10°, 95% CI=0.40-1.80, $t_{151} = 3.01$, $p < .01$).

2.3.2.4 *Gain*

The palm-board in this study recorded a gain of 0.74 (95% CI= 0.67 – 0.80) which is comparable with Proffitt's palm-board which had a gain of 0.73 (95% CI= 0.67-0.79) (Proffitt et al, 1995). The PCI has a higher gain, 0.86 (95% CI= 0.79 – 0.93), but the difference between the two measures did not reach significance.

2.3.3 *Discussion*

Results suggest that 'haptic' measures of geographical slant were relatively accurate, in line with Proffitt's account (Proffitt et al., 1995; 2006). Additionally, the palm-board data replicated the pattern of the original normative data of Proffitt et al. (1995), overestimation at shallow slopes contrasted with underestimation for the steeper slopes (≥23°). Data for the new PCI measure which allowed use of the shoulder, elbow and wrist joints, revealed estimates that did not differ from the actual slant angle of inclines between 19° and 31°. This suggests that the PCI may be better suited to judging the slant of steeper slopes, such as the real-world stimuli of public access staircases for which it was designed. It is of note that the CoVs of both measures in this study were considerably lower than those obtained by Durgin et al. (2010) for the palm-board, suggesting that the concerns raised by Proffitt & Zadra (2011) about the palm-board measures used by Durgin et al. (2010) may be warranted.

2.4 Experiment 2

The results of experiment 1 showed that PCI estimates of steep hills and staircases did not differ from the actual angle of the slopes. Nonetheless, the accuracy of PCI judgements was not tested for near surfaces, a condition under which Durgin and colleagues questioned the accuracy of 'haptic' measures. Previously, Durgin et al (2010, experiment 1) tested free-hand matching of the slant of a 30° block positioned on a table in front of participants against 'haptic' matching with a replica of Proffitt's palm-board measure. Here, we replicate this experiment but replace the free-hand measure with the PCI, and include a second block of 25° to test the sensitivity of the two measures to differences in slant angle of 5°.

2.4.1 *Methods*

A within-subject design was used to compare estimates of slant between the PCI and palm-board. The order in which participants judged slant between the two blocks and two measures was counterbalanced throughout.

2.4.1.1 *Participants*

Twenty participants (ten male) took part in the study after responding to an e-mail offering a free snack in return for short study on perception. Participants were all non-academic staff members or students of the University of Birmingham and naïve to the purpose of the research.

2.4.1.2 *Stimuli and apparatus*

The stimuli for perceptual judgements were slanted polystyrene blocks. Block 1 (30°) had the same dimensions as the block used in Durgin et al's original experiment, a width of 30cm and length of 45cm. Block 2 measured the same width and length as Block 1, the only difference being that its slant was 25°. The PCI and palm-board apparatus used to make slant judgements were the same as in experiment 1.

2.4.1.3 *Set-up and procedure*

Slanted blocks were positioned on a 1.2 meter high table in front of participants who stood 70cm back from the block they were judging. The two blocks were positioned side by side on the table, 30cm apart and were hidden from view until the participant was ready to begin with their judgements. Only one block was on view at any one time. An exception from methodology used by Durgin et al. (2010) was how each participant's view of their hand was obscured while adjusting 'haptic' measures. Rather than placing a the large board between participants and the palm-board that extended down to the table surface (approx. 94cm high x 59 cm wide; see Durgin et al., 2010, Fig. 2), participants wore a head mounted board to block view of the hand (40cm high x 26cm wide), as show in Fig. 5, which could not restrict movement of the arm or hand.

Each participant provided estimates of the two blocks using both pieces of apparatus. Prior to making judgements, the palm-board and PCI were both adjusted to slightly above the participant's waist level to allow for as full a range of movement as possible. The participant was told which apparatus they would be using first and stood to its left before the block in front of them was revealed. After making their first estimate, the block was recovered with the cloth, and the participant moved onto the next piece of apparatus set-up in front of the other block, which remained hidden until the participant was in the correct position. Once an estimate had been made with both pieces of apparatus, the participant turned away while the experimenter switched the positions of PCI and palm-board. Markings on the floor ensured the apparatus were moved to the same position each time, central to either block, 70cm back from its base. In total, each participant made four judgements of slant in a counterbalanced order.

Figure 2.5. A photograph of the set-up used in experiment 2. The participant is shown wearing a novel device that hides their hand from view while making palm-board judgements without restricting their arm or wrist movement.

2.4.2 *Results and discussion*

2.4.2.1 *Statistics*

Inspection of boxplots revealed no outliers. Repeated-measures analyses employed two between-subject factors of Gender and Order with a single within-subject factor of Measure (PCI and Palm-Board). As in experiment 1, the data were the errors of slant estimates across the different slopes by subtracting the actual slant of the block being judged from the value of each estimate.

2.4.2.2 *Results*

The ANOVA contained a within-subject effect of Measure ($F(1, 12) = 5.77$, $p < .05$) such that PCI estimates were reliably higher than those made with the palm-board across both slopes. No between-subject main effects were revealed for Order or Gender (both $p > .69$), nor did the effect of Measure interact with either factor (both $p > .18$).

Follow-up one sample t-tests with Bonferroni correction revealed that PCI estimates did not differ significantly from the actual slant angle of either Block 1 (mean error=-2.89, SE=1.56, t_{19}= 1.84, p = .25) or Block 2 (mean error=-1.78, SE=1.29, t_{19} = 1.38, p = .55). Palm-board estimates, however, reliably underestimated the slant of Block 1 (mean error=-6.18, SE=1.88, t_{19} = 3.29, $p < .05$) and Block 2 (mean error=-4.77, SE=1.20, t_{19} = 3.97, $p < .01$).

Raw means, average error, 95% CIs and CoVs, calculated in the same manner as in experiment 1, are presented in Table 2. A further set of paired-samples t-tests were run between the mean estimates of Blocks 1 and 2 with the PCI and the palm-board in order to test the sensitivity of the two measures for a difference in slant angle of 5°. Results revealed that both PCI (t_{19} = 2.22, $p < .05$) and palm-board (t_{19} = 2.28, $p < .05$) estimates differed significantly between the two blocks, demonstrating sensitivity of both measures to this 5° difference in slant angle.

Table 2.2 A summary of PCI and palm-board estimates, mean errors, 95% CIs and Coefficients of Variation (CoV) for experiment 2.

Block	Measure	Mean Estimate	Error	95% CIs	CoV
1 (30°)	PCI	27.11	-2.89	-6.17 – 0.40	0.293
	Palm-board	23.82	-6.18	-10.11 – -2.25	0.352
2 (25°)	PCI	23.22	-1.78	-4.49 – 0.93	0.246
	Palm-board	20.23	-4.77	-7.28 – -2.26	0.261

CIs = Confidence Intervals, CoV=Coefficient of Variation.

2.4.2.3 *Discussion*

In this partial replication of Durgin et al.'s (2010) test of slant perception in near space (experiment 1), 'haptic' measures for the blocks revealed the same pattern of results seen in the field. PCI estimates did not differ from the actual angle of the blocks whereas the palm-board data underestimated the slant. While the magnitude of the underestimations with the PCI, (30° = -2.89, 25° = -1.78), were somewhat larger than for the field data, the CIs for the 30° and 25° block overlapped with those for the slightly steeper slopes in the field, 31° and 26°. These data do not suggest any major differences between near and far space. Once again, CoVs for the palm-board and the PCI were less noisy than those reported for the palm-board by Durgin et al (2010). In addition, slant judgements made with the palm-board and the PCI, were sensitive to a difference of 5° in slant angle, with a relatively small sample (n=20), suggesting any noise was not impeding sensitivity.

2.5 General Discussion

2.5.1. *Accuracy of the palm-board and PCI*

The action involved when adjusting the PCI differs from that of the palm-board as it requires a directed movement towards the slant stimulus, rather than away. Nonetheless, the resulting slant estimates are similar to those obtained with the palm-board, suggesting the two devices may tap into the same perceptual process. In line with Proffitt's data, 'haptic' judgements of traversable slopes were *relatively* accurate, with appreciably lower magnitudes of difference from the actual slant when compared with verbal and visual measures reported by others. The PCI is not constrained by wrist flexion. Adjustments of the surface can employ motion of the hand, the elbow and the shoulder. Consequently, the PCI should circumvent Durgin and colleagues' concerns about over reliance on wrist flexion for a 'haptic' measure of slant. While motion *is* constrained in the lateral plane, i.e., perpendicular to the surface, it is not in the vertical plane of interest. Under these conditions, the PCI was accurate for the steep slopes characteristic of stairs in the built environment, both in the field and in near space.

Durgin et al.'s (2010) average palm-board estimate for a 24.5° outdoor hill viewed at eye level in experiment 2 was 18.1°. Linear interpolation for the palm-board used here for a 24.5° hill suggests an average of 22.2° would have been obtained whereas interpolation from Proffitt et al.'s (1995) normative data suggests an average estimate of 23.6° with their palm-board. Both these estimates are of larger magnitude than the measure obtained by Durgin and co-workers. Concerning the 30° block in Durgin et al.'s (2010) experiment 1, the average palm-board estimate of 19.4° was also lower than the average of 23.8° for the 30° block in this study. Additionally, the CoVs of the palm-board in both studies presented here were considerably lower than those reported by Durgin et al. (2010) for experiments 1 and 2. Proffitt & Zadra (2011) raised concerns about the apparatus used in Durgin et al's experiments, suggesting the palm-board might have been more difficult to adjust than Proffitt's. Inspection of Fig. 2 of Durgin et al. (2010) suggests a possible explanation. This figure reveals a large board (approx. 94cm high x 59 cm wide) that extended down to the table surface was positioned between the participant and the palm-board. The function of this board was to obscure vision of the hand both for free hand and palm-board measures. In the current study, participants wore a smaller head mounted board to block view of the hand (40cm high x 26cm wide) but allow free use of the hand and arm while adjusting the 'haptic' measures. This head mounted display was associated with smaller CoVs than reported by Durgin et al (2010), with magnitudes comparable to those reported for their free-hand measure. It is possible that the large board may have interfered with freedom of movement for some participants, producing both lower overall 'haptic' judgments and higher variation of these estimates for the indoor block and the outdoor hill (Durgin et al., 2010, experiments 1 and 2).

2.5.2. *Free-hand matching*

The alternative measure of slant to the palm-board proposed by Durgin and colleagues was free-hand matching. Participants orientate their hand freely by their side until they feel as though their palm is in line with the surface facing them. The angle of the palm is measured using motion capture when in the laboratory (experiments 1 and 3, Durgin et al., 2010) or photographs when in the field (experiment 2, Durgin et al., 2010). Durgin et al. (2010) reported that free-hand matching of near surfaces was accurate (experiments 1 and 3, Durgin et al., 2010). In contrast, free-hand matches of the one hill tested reliably overestimated the hill's slant (experiment 2, Durgin et al., 2010), though not to the extent of verbal reports. In an earlier study, Bridgeman & Hoover (2008) measured perceived geographical slant with a conceptually similar style of free-hand matching. Bridgeman & Hoover's participants were instructed to hold their elbow against their body, start with their foreman perpendicular to the body, and raise and lower the forearm until it matched the slant of the hill. Resulting estimates were, once again, overestimations of the actual angle of the hill.

As noted in the introduction, 'haptic' measures with palm-boards are relatively accurate when compared with what are termed explicit estimates of slant exemplified by verbal and visual measures. Fig. 6 summarises the estimates for free-hand matching of outdoor hills and the data from experiment 1 here for outdoor slopes obtained with the palm-board and the PCI. For comparison purposes, the visual matching data from Proffitt et al., (1995) have been included to illustrate the relative accuracy of 'haptic' measures and free-hand matches when compared to the actual slope and visual matching. For the 'visual' measure, developed by Proffitt et al. (1995), participants reproduce the cross-section of the hill with a moveable segment of a disk, depicted in Fig. 7. This summary suggests the 'haptic' measures of slant better approximated the slant for outdoor slopes than the sparse data on free-hand matching, and do so even when possible constraints imposed by wrist flexion that might make it 'accidentally accurate' were removed. An accurate 'haptic' measure of geographical slant for real-world stimuli is a pre-requisite for any potential test of dissociation. The data here suggest the PCI provides this for slopes between 19° and 31°.

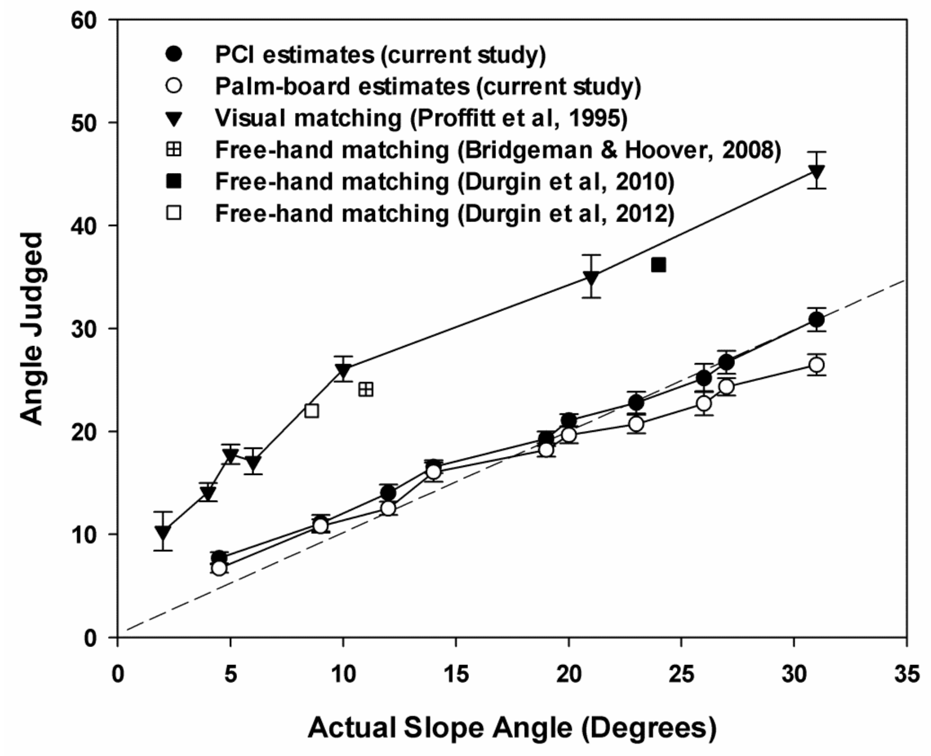

Figure 2.6. A plot to allow comparison of PCI and palm-board judgements from the current study with normative visual matching data (Proffitt et al., 1995), and free-hand matching data from Bridgeman & Hoover (2008) for an 11° hill, Durgin et al. (2010) for a 24.5° hill and Durgin et al. (2012) for a 8.6° hill

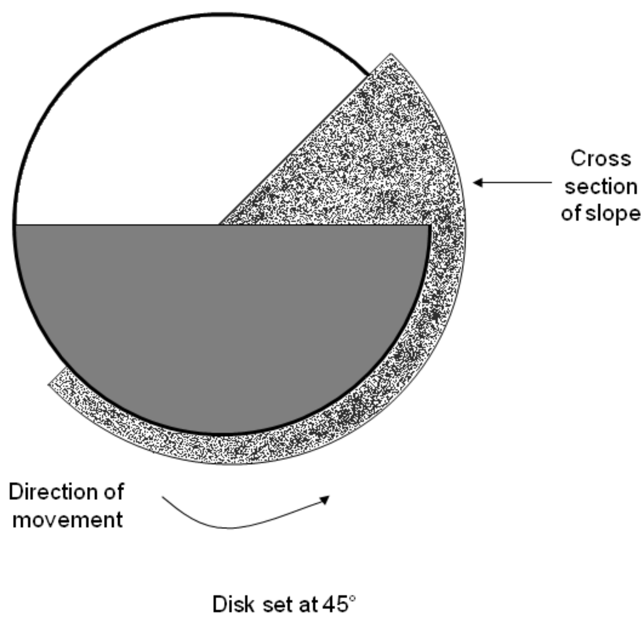

Figure 2.7. The disk device used as for 'visual' estimates in geographical slant research

2.5.3. Practical benefits of the PCI

The measurement system for the PCI is efficient and reliable. An electronic inclinometer provides the judged angle to one decimal place on an LCD display out of view of the participant, but in direct view of the experimenter. Recording of PCI estimates is reliable and straight forward, both in the field and a laboratory setting. There are no attachments to participants' hands that might act as barriers to recruitment in the field (c.f. Durgin et al., 2010; Li & Durgin, 2011). Additionally, one of the shortcomings of palm-boards is that participants can see their hand whilst adjusting the apparatus, even if instructed not to look. Free-hand matching has the same drawback, requiring some occluding apparatus to block the participant's view of their hand during perceptual judgements. The PCI's integration into a box set-up hides the palm more efficiently. These factors make the PCI a more tractable measure of perceived geographical slant than free-hand matching.

2.5.4 *Conclusion*

Our results do not speak to the debate on dissociation between explicit judgements of geographical slant, and 'haptic' measures. The current pair of experiments do, however, provide support for the relative accuracy of 'haptically' measured geographical slant, in line with Proffitt's original conception. The improved measure of the PCI for geographical slant that makes use of the shoulder and elbows joints, as well as the wrist joint, provided estimates that were consistent with the physical incline of the real-world stimuli of steep hills and staircases for which it was designed.

2.6 Acknowledgements

The research team would like to thank Dr. Dave McIntyre and Steve Allen for their assistance with the construction and maintenance of the PCI, as well as the palm-board measure used in the current study.

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CHAPTER 3

The publication presented in chapter two prompted a response from the central figure of opposition to Proffitt's model of geographical slant perception, Professor Frank Durgin. In his paper, Durgin summarised his viewpoint on why he believed 'haptic' measures of geographical slant perception to be invalid, and partially replicated one of his experiments in order to demonstrate his alternative account. Here, our response to Durgin's rebuttal focuses on the inconsistencies in data he uses to oppose Proffitt's model, and outlines a perceptual explanation for such discrepant findings between his and Proffitt's research groups.

PAPER 2

WHAT DO HANDS KNOW ABOUT OBJECTS? TAKING PERCEPTION OF HILLS OUT OF CONTEXT: A RESPONSE TO DURGIN (2013)

Taylor-Covill, G. A. H. & Eves, F. F. (2013). *Acta Psychologica*

3.0 What do hands know about objects? Taking perception of hills out of context: A response to Durgin (2013)

3.1 Abstract

In a recent paper, we provided independent evidence on the accuracy of 'haptically' measured geographical slant perception (Taylor-Covill & Eves, 2013). Durgin (2013) argues that the devices used in our work, namely the palm-board, and palm-controlled inclinometer (PCI), are not measures of perception. In response, we outline four failures of replication in the laboratory work of Durgin and colleagues on which they base their model of slant perception. We also highlight fundamental differences between the perceptual tasks Durgin and colleagues ask of participants relative to those of Proffitt and colleagues' traditional measures. These subtle differences might help explain how the two groups have arrived at discrepant conclusions.

3.2 Measuring the Slant of Real World Stimuli

In reply to our paper, Durgin (2013) provides an extended summary of the position taken by himself and his colleagues on the issue of haptic estimates of geographical slant. We doubt this summary is of any relevance to our work with the real world stimuli of hills and staircases. As far as we can tell, Professor Durgin and colleagues have collected data on haptic estimates with palm-boards for only three real world hills. As we noted in the paper, we had concerns about the veracity of the palm-board data that were collected for the solitary hill reported in Durgin, Hajnal, Li, Tonge & Stigliani (2010). Durgin's reply to our paper has directed us to data for two further hills reported in a book chapter (Durgin, Ruff & Russell, 2012a). As we document later, these new data appear equally problematic.

The rest of Professor Durgin and colleagues' alternative model is based primarily on data for judgements made in near space, with particular emphasis placed on the free-hand matching technique that they espouse. It would be surprising if a free-hand was not accurate in near space given its potential for contact with the surface. Concerning real world hills in far space, however, the two available studies for free-hand matching report considerable overestimation; 36.1° for a 24.5° hill (Durgin, Hajnal, Li, Tonge, & Stigliani, 2010) and 22.0° for an 8.6° hill (Durgin, Klein, Spiegel, Strawser & Williams, 2012b). As we illustrated in figure 6 of the paper, the magnitude of these free-hand overestimates for the slopes of real-world stimuli is similar to that obtained with visual matching in the original research (Proffitt, Bhalla, Gossweiler, & Midgett, 1995). Thus, free-hand matching does not appear accurate for far space stimuli (see also Bridgeman & Hoover, 2008). While Durgin and colleagues suggest effects of viewing distance from the slope can explain large magnitude discrepancies between near and far space, our data do not confirm this suggestion. Formal tests of the effects of distance from real staircases, 1m vs. 15m and 5m vs. 34m, indicate increases in measured slope in the range +4.2° to +1.3° for verbal, visual and haptic estimates, with no significant interaction between measure and distance in either study (Eves, Taylor-Covill & Thorpe, submitted). Further, Durgin (2013) uses distance from the surface to explain the overestimation of palm-boards for relatively shallow real world hills; the increases for haptic measures in these formal tests of the effects of distance were modest, +2.2° and +1.3°. Actual data do not match Durgin and colleagues' modelling.

3.3 Four Failures of Replication

Our haptic measures with either the palm-board or the palm-controlled inclinometer do not provide evidence of *appreciable* differences in accuracy between blocks in near space and real world hills and staircases in far space. In particular, the percentage estimation in our palm-board data of the angle for a 25° block [M = 80.9, 95% Confidence Interval (CI) = 70.9, 92.2] overlapped with that for a 26° hill (M = 87.3, 95% CI = 78.2, 96.6), as did the percentage estimation of a 30° block (M = 79.4, 95% CI = 66.3, 92.5) with a 31° hill (M = 85.4, 95% CI = 78.7, 92.2). Our estimate for a 30° block, 79.4%, *was* lower than predicted from linear interpolation of the far space stimuli (87.4%) but greater than the 64.7% obtained with the problematic palm-board set up of Durgin et al., (2010). We did not replicate major differences between near and far space for these haptic measures of slant, even when the potential constraints of wrist flexion were removed with the palm-controlled inclinometer. Similarly, we did not replicate the elevated coefficients of variation for palm-boards reported by Durgin and colleagues (2010). As noted in the paper, we suspect that the relatively large board used to preclude vision would have constrained adjustment of a waist high palm-board for some participants, artefactually lowering their estimates. Such an effect would elevate the coefficient of variation of the group. There is a third failure of replication that we document below.

Our formal comparison of the two haptic measures over a range of angles (4.5° - 31°) replicated the pattern of Proffitt et al.'s results for the palm-board, overestimation at shallow angles and underestimation above 20°. The data of Schnall, Zadra & Proffitt (2010) revealed a similar pattern in that overestimation for a 5.6° hill contrasted with underestimation for a 29° hill. Table 1 below compares the percentage over and underestimation for the angles we tested in experiment 1 with the original data from

Proffitt et al. (1995) and from three studies employed by Durgin and colleagues to develop their alternative model [Experiment 3, blocks viewed from 0.7 m, Durgin et al., (2010); blocks viewed from 0.5 m and 1.5 m, Li & Durgin, (2011)]. We used linear interpolation of the data from each of these studies by other researchers to estimate the angle before converting to a percentage.

Table 3.1 Percentage over- and underestimation of the actual angle of hills with the palm-board in Taylor-Covill & Eves (2013, Experiment 1) compared with interpolated data from previous studies.

Actual Angle	4.5°	9°	12°	14°	19°	20°	23°	26°	27°	31°
Taylor-Covill & Eves (2013)	149%	120%	104%	115%	96%	99%	90%	87%	90%	85%
Proffitt et al., (1995)	201%	137%	121%	114%	103%	101%	98%	95%	94%	91%
Durgin et al., (2010)	61%	61%	61%	61%	61%	61%	61%	61%	61%	61%
Li & Durgin (2011) 0.5m	-83%	5%	27%	36%	51%	53%	59%	64%	64%	67%
Li & Durgin (2011) 1.5m	-66%	7%	27%	33%	47%	50%	53%	56%	56%	59%

As can be seen, laboratory data from Durgin and colleagues with the improved, non-frictional palm-board failed to replicate the overestimation at shallow angles reported by Proffitt in the original research with real-world hills, a pattern replicated in our first study. Instead, underestimation occurred for all studied angles, with estimated averages of 61% in Durgin et al (2010), followed by 34% and 32% when viewed from distances of 0.5m and 1.5m respectively in Li and Durgin, (2011). As noted earlier, we did not find major differences between near and far space with palm-boards in experiment 2 that could be used to explain the discrepant data from Durgin's group. The additional data provided by Durgin (2013) confirm these discrepancies; palm-board measures at waist height underestimated a 32° surface, averaging 51% and 46% of its actual angle for distances at 0.7 m and 4.5 m respectively. Implying, as Durgin (2013) appears to, that multifarious effects of palm-board procedure might explain these discrepancies is specious. Participants adjusted a palm-board positioned just above waist height with their right hand. That was sufficient to replicate the pattern for real world stimuli.

There seem two possible factors that might reconcile these discrepancies, one empirical and the other more paradigmatic. First, our data provide an independent replication of the pattern of palm-board results of Proffitt's group for real world stimuli and independent corroboration of the work of Durgin and colleagues has yet to be provided, except for the overestimation of angle with free-hand matches for hills (Bridgeman & Hoover, 2008). Further, predicting palm-board settings for hills from near space stimuli (e.g. Figure 2, Durgin, 2013), is no substitute for collection of actual data for hills which would seem an appropriate way to attempt replication of Proffitt et al., (1995). As far as we knew when writing the paper, Durgin and colleagues had been content to question the data for real world stimuli without any meaningful attempt at such a replication. The rejoinder to our paper, however, alerted us to unknown palm-board data for two real hills (Durgin et al., 2012a). Full results are not provided as the source is a book chapter. Participants made palm-board estimates, followed by verbal ones, of the slopes of 18.5° and 21.5° hills; only data averaged across the two hills are available. The average slope of 19.8° was estimated verbally as 45.5° and, on average, as 31.5° with the palm-board. Disappointingly, the free-hand matching data that could be compared to Durgin et al., (2010, 2012b), and Bridgeman and Hoover (2008), were omitted. With the problematic set-up of Durgin et al., (2010), haptic estimates were 74% of an 18.1° hill yet the improved measure estimated 159% of a 19.8° hill.

Measuring at chest height is supposed to improve accuracy (Durgin, 2013) but the magnitude of this discontinuity from significant underestimation to overestimation of slant for a 1.7° change in actual angle is disconcerting. While Durgin uses these data to claim that underestimation 'is not intrinsic to the mechanics of the palm board itself' (page 15, Durgin, 2013), they are seriously discrepant from other data. From our viewpoint, this represents a fourth failure of replication of other research with palm-boards. As can be seen from table 1, both our own palm-board and Proffitt's were accurate for a hill of 20°. We have obtained 'haptic' estimates of slopes from more than 2,000 participants in nine different studies only one of which is currently available (Taylor-Covill & Eves, 2013). We do not find overestimation of this ilk around this angle, even when participants make judgements some 34 m from the slope. These newly inspected data for hills with Durgin's palm-board procedure are errant, as were the earlier ones.

3.4 Perception of Near and Far Space Surfaces

While Durgin and colleagues have been unable to replicate other's data for real hills, the consistency of differences in palm-board estimates between laboratory and real world stimuli suggests they must be considered real and not artefactual. Concerning this paradigm, if we assume Durgin and co-workers' palm-board data for real world hills can be discounted, then the discrepancies between the two lines of research might be reconcilable. The two groups have asked fundamentally different perceptual tasks of their participants. Durgin and colleagues' research is primarily for near space perception of relatively small objects, whereas our work, and that of Proffitt and colleagues, involves perception of real world stimuli that extend from the ground on which the perceiver stands to above eye-height.

Durgin and co-workers obtain haptic measures of slant for surfaces of about 40 cm extent either placed on a table (experiment 1: Durgin et al, 2010) or elevated above the ground plane at approximately chest level (experiment 3; Durgin et al., 2010; Li & Durgin, 2011). The majority of these surfaces are explicitly positioned within touching distance. The usual task for a near space perceiver is to inspect, and possibly grasp, an object they have positioned in near space by approaching it. It is unclear whether the perception investigated by Durgin and his colleagues is about geographical slant perception in general or about the apparent surface of an object. We suspect the latter; the accuracy of a free-hand in near space is a necessity if the world is not to be littered with broken objects. The perception benefits from improved acuity and sensitivity of binocular vision relative to far space, as well as increased attentional resources (Dufour & Touzalin, 2008; Kao & Goodale, 2009; Reed, Betz, Garza & Roberts, 2010), even when the hand itself is not visible (Abrams, Davoli, Du, Knapp, & Paull, 2008). Additionally, the neuropsychological organisation of near space perception is biased towards object properties relevant to the task in hand (Bjoertomt, Cowey & Walsh, 2002; Goodale & Milner, 1992; Gozli, West & Pratt, 2012; Previc, 1998). Even when these surfaces have been positioned out of reach (Experiment 2, Li & Durgin, 2011; Durgin, 2013), they are elevated above and divorced from the ground plane. As Proffitt and Zadra (2011) pointed out, these are not surfaces with which the human locomotor system could interact. They do not intersect the ground plane on which the perceiver stands, nor does it seem likely that they could imply intersection when their irregular outline is superimposed on a background of uniform colour. The surfaces are too small to be walk-on-able and too elevated to be climbable with a bipedal gait (Warren, 1984).

While they might be too large to be grasped by a single hand, they may still appear as objects segregated from their background and graspable by two hands; their maximal extent is only half as much again as that of a human foot.

There is a related fundamental difference between the perceptual task facing observers in Durgin and colleagues work and those perceiving real-world stimuli. For near space, and for isolated surfaces positioned above the ground plane but outside of reach, the stimulus represents a foreground object positioned against a background. When standing at the base of a real world hill or staircase, however, the background is the stimulus. Part of this background may become the foreground when no fixation point is specified about which perceptual judgements should be made. There are two separate sequellae of this distinction. First, we cannot explain why the data obtained with palm-boards in Durgin's laboratory studies consistently underestimate the actual surface of the object. Nonetheless, a hand positioned at waist height is not in transit to the object and would only need to be accurate at some later time when approach was imminent (see figure 2.6, chapter 2). Second, using a palm-board to indicate the surface slant of a relatively small object is quite a different task from using a palm-board to indicate the slant of the landscape within which such an object might be placed. In many cases, the real-world stimulus will occupy most of the visual world of the perceiver. It is possible that the gist of the whole visual landscape can be better approximated by a hand adjustment in the periphery of the visual field than a free-hand positioned more centrally for far space stimuli.

If we understand Durgin and colleagues position correctly, it assumes a generality of hand gestures to indicate the perception of slant for touchable objects in near space and those outside it that one would be likely to touch, only should one fall when traversing them or wish to sit upon them. We can think of no reason why this assumption of generality should be true and a number of reasons why it might not be. We are unsure of the relevance of any of this laboratory work, and any theory derived from it, to the real-world stimuli in which we are interested. Others might have described this as air psychology and it is certainly not a field in which we are likely to step.

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CHAPTER 4

Chapters two and three provided evidence and explanation for the accuracy of haptically perceived geographical slant. This aspect of Proffitt's model of perception was shown to generalise to the perception of staircases. The paper in this chapter tests how the rest of his model generalises to an alternative environment that might be used to further investigate the relationship between resources and perception in a laboratory environment.

PAPER 3

SLANT PERCEPTION FOR STAIRS AND SCREENS: EFFECTS OF SEX AND FATIGUE IN A LABORATORY ENVIRONMENT

Taylor-Covill, G. A. H. & Eves, F. F. (2013). *Perception, 42,* 459-469.

4.0 Slant perception for stairs and screens: Effects of sex and fatigue in a laboratory environment

4.1 Abstract

The apparent slope of a hill or staircase, termed geographical slant perception, is exaggerated in explicit awareness. Across two experiments, this paper tests the use of a laboratory environment to study geographical slant perception. First, using a student aged sample (n=166), we examine the similarity of slant estimates in the field with those made in the laboratory using life-sized images of the built environment as stimuli. Results reveal no differences in slant estimates between the two test environments. Furthermore, three traditional measures of perceived geographical slant (verbal, visual and haptic) appear sensitive to a difference in slant of only 3.4° in both the field and laboratory environments. In a follow-up experiment, we test the effect of fatigue on slant estimates in the laboratory. In line with previous research with outdoor stimuli, fatigued participants provided more exaggerated explicit reports of slant relative to those in a control group, and females gave more exaggerated slant estimates than males across both experiments. The current set of findings open the door to future studies of geographical slant perception that may be more suited to laboratory conditions.

4.2 Introduction

When navigating the environment, a hill or a staircase represents a significant locomotor challenge. The apparent visual steepness of such obstacles, termed geographical slant perception, is exaggerated in explicit awareness (Kammann, 1967;

Proffitt et al., 1995). Proffitt has often cited the example of an observer viewing a 5° hill, who will generally report it as 20° in slant angle when viewed from its base (Proffitt et al., 1995). More recent studies have used staircases as stimuli for testing slant perception in the built environment. Consistent with perception of hills, explicit reports of staircase steepness are also grossly exaggerated (Shaffer & Flint, 2011).

Explicit perception of hill or staircase slant is measured through verbal reports and visual matching estimates. Verbal reports of slant angle are given in degrees relative to the horizontal. Visual matching requires participants to adjust a moveable segment of a disk (Figure 1a) so that the angle of the segment matches the perceived cross-section of the slope. In contrast to explicit measures, haptic judgements, which involve making a visually guided motor action to match the slope of a hill or staircase, reveal more accurate estimates (Proffitt et al., 1995; Proffitt & Zadra 2011; Taylor-Covill & Eves, in press).

Previous research has reported that explicit estimates of geographical slant become more exaggerated when locomotor resources are depleted, while haptic judgements are unaffected. Bhalla & Proffitt (1999) found that when they manipulated climbing effort by encumbering participants with a heavy backpack, containing 16.7-20% of their bodyweight, verbal and visual measures of hill slant increased. Furthermore, Proffitt et al. (1995) tested depletion of resources after participants had completed an exhausting run around their university campus. As with increased weight, fatigue brought on by running resulted in more exaggerated verbal and visual estimates of hill slant, a finding replicated by Bhalla & Proffitt (1999). Haptic judgements in these experiments however, did not show any significant change post-fatigue. Recent reports question these findings. Durgin & colleagues (2009) argue the results of such manipulation studies could be put down to influences of experimental demand (Orne, 1962). They reason that after being encumbered with a heavy backpack, a participant might deduce that they are expected to report a hill as steeper (Durgin et al., 2009). Similarly, fatigued participants after a run may expect some influence on their perception and give steeper estimates at the end of the run than at its outset (Durgin et al., 2010).

Explicit reports of geographical slant also appear to be influenced by demographic grouping. Proffitt et al. (1995) reported that females gave steeper verbal and visual estimates of geographical slant than men across a range of hills. Additionally, increasing age and decreasing health have been reported to increase slant estimates (Bhalla & Proffitt, 1999). As with the manipulation studies, Durgin et al. (2010) argue that demand characteristics provide an alternative explanation for the results. Requesting participants to make judgments based on the 'walkability of the hills for a person their age' (Bhalla & Proffitt, 1999, page 1008) could have introduced experimental demand for some elderly participants. Sex differences in reported slant, however, have prompted little comment.

Developing new approaches to testing geographical slant perception might help to resolve the ongoing debate surrounding potential effects of resource depletion. Many of the challenges to the work of Proffitt and co-workers are based on results of laboratory studies that used surfaces that represent either none or relatively minor locomotor challenges (Durgin et al., 2009). If, however, perception of life-sized displays of real world stimuli could be studied in the laboratory, greater experimental control would be possible. In particular, balancing for demographics effects, more standardised manipulations of resources and greater exploration of potential effects of demand could be achieved.

Real-world sized displays have been explored in previous research. For example, Proffitt et al. (1995) completed two experiments in which hill estimates were made in virtual reality. Verbal and haptic judgements were well-matched to those made for real hills. Creem-Regehr et al. (2004) had participants make slant judgements on a treadmill which was linked to a 2.44 metre high display of hilly terrain (approximately 180° field of view). Participants reported hills as steeper when walking with the appropriate effort required for scaling the presented slopes (Creem-Regehr et al., 2004). In a series of experiments that pre-date the detailed study of geographical slant, Warren (1984) used projected slides of stairs as stimuli on a 1.22m wide x 1.83m high screen to test the theory of affordances. Participants were able to detect the critical riser height of steps, i.e. the point at which they were unable to climb using bipedal locomotion, which matched their biomechanical constraints for the task, and a preferred riser height that matched their minima of energy expenditure during climbing (Warren, 1984). Feresin & Agostini (2007) compared slant estimates for natural stimuli in the field with those made viewing stereoscopic slides in a laboratory. While this study was limited to a single 'visual-kinesthetic measure' involving a paddle-board to judge slant, the authors reported equivalent 'haptic' measures for laboratory and field stimuli when binocular disparity information was available.

While virtual reality and interactive treadmill setups were successful in expanding our knowledge of geographical slant perception, they are both expensive and/or inaccessible for many researchers. Furthermore, no previous laboratory based study has included a formal comparison between the same stimuli presented in the field and the laboratory for all three measures of geographical slant perception. In this paper, two studies used a laboratory setup of life-sized images of the built environment to test principles of geographical slant perception in a lower-cost laboratory setting. In experiment 1, verbal, visual and haptic measures were obtained in the field across two sets of stairs (15° and 18.4°), and compared with estimates made to life-size images of the same stairs presented in the laboratory. By using two staircases with only a small difference in slant we could test sensitivity of verbal, visual and haptic reports in the field and the laboratory. In experiment 2, one group of participants were fatigued with a maximal fitness test, completed immediately before they made judgements of a life-size staircase image in the laboratory. A control group provided judgements of the same image without prior fatigue. The findings are compared with previous investigations into fatigue and perception (Bhalla & Proffitt, 1999; Proffitt et al., 1995).

4.3 Experiment 1

Experiment 1 included two test settings, the natural environment (field test condition) and a laboratory environment using life-sized projected images of the same staircases used in the field test (laboratory condition). Participants viewed one of two staircases in either condition. This design allowed us to test the equivalence of geographical slant estimates between the field test and a laboratory condition. By using two staircases that differed by only 3.4° it was also possible to test the sensitivity of geographical slant perception measures to a small change in incline across the two environments. We predicted greater estimates for Staircase 2 (18.4°) than Staircase 1 (15°). In addition, by using a student-aged sample with even numbers of males and females across conditions we could effectively test the effect of sex on perception in the field and laboratory while controlling for influences of age and health.

4.3.1 *Method*

4.3.1.1 *Stimuli*

Staircase 1 (15.0°, 1.1m high) consisted of eleven steps while Staircase 2 (18.4°, 1.6m high) consisted of twelve steps. In both the field and laboratory conditions, participants gave perceptual judgements 3.6m back from the base of the staircase. Although studies on geographical slant would normally take judgments at the base of a hill, it was necessary for participants in this study to stand back from the stairs as the participants in the laboratory condition would have to stand back from the projection screen to avoid occluding the image.

4.3.1.2 *Participants*

A total of 166 University of Birmingham students (age, M=20.38 years, SD=1.88 years) took part in the study across the two testing environments. Eighty three participants in the field test (43 male) were recruited whilst walking by either Staircase 1 (N=43) or Staircase 2 (N=40) and were asked if they could spare five minutes for a short study of perception in the built environment. An equal sample of eighty-three participants were recruited for the laboratory test after responding to an advertisement on the University of Birmingham's student website for a five minute perception test and received either £2.00 or a fast food voucher in exchange for participation. All participants had normal or corrected-to-normal vision and were screened prior to testing for any illness, injury or fatigue that might affect perceptual judgements.

4.3.1.3 *Field setting*

4.3.1.3.1 *Measures and procedure.*

Participants provided three estimates of geographical slant; verbal, visual and haptic. The verbal measure required participants to estimate the apparent slant angle of the staircase in degrees relative to the horizontal. For the visual measure, participants were handed a disk with a hidden protractor on the reverse (Figure 1a) and instructed to adjust the black segment until it matched their perceived angle of the staircase in cross-section. The matched angle could then be read on the reverse of the disk from a protractor by the experimenter. For the haptic measure, participants made a visually guided motor action towards the staircase using the Palm-Controlled Inclinometer, Taylor-Covill & Eves, in press), pictured in Figure 1b. Participants were instructed to place their palm on the bottom plate of an underslung pendulum, which was housed inside the metal box, and to gaze forward at the stairs while swinging the plate forward until it felt as though their palm was in line with the slope of the staircase. The PCI has been shown to be a sensitive measure of slant perception with a coefficient of variation comparable with non-restrictive proprioceptive measures such as free-hand matching (Taylor-Covill & Eves, in press).

In order to test the reliability of participants' slant estimates, a new measure of angle knowledge was included. After providing perceptual judgements, participants were instructed to turn away from the staircase and were handed the same unmarked disk used for the visual measure. Participants were then instructed to recreate a 30° angle as accurately as possible and were given a 10° range of error to avoid being excluded from analyses. Finally, the experimenter asked participants to fill in their age, gender and height on a corresponding sheet, handed the participant a summary of the purpose of the research and obtained consent for their data to be included. The experimenter answered any subsequent questions asked by the participants.

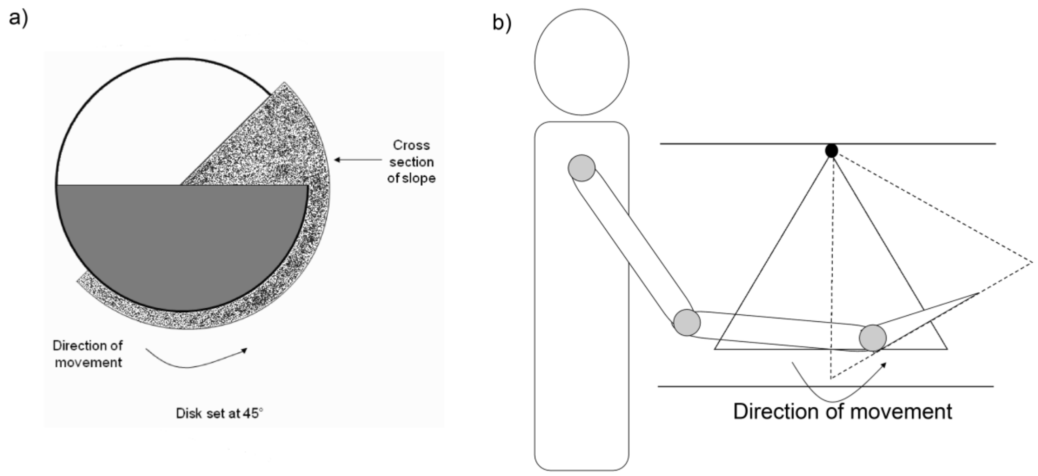

Figure 4.1. Schematics of the visual disk (a) and Palm-Controlled Inclinometer (b).

4.3.1.4 *Laboratory setting*

4.3.1.4.1 *Set-up and equipment*

The images used in the laboratory test were uploaded digital photographs of the staircases used in the field test. A 5.0 megapixel Olympus ‘Camedia’ C-5050 digital camera captured staircase photographs from 3.6 metres back (the distance from which participants viewed the staircases in the field test) and at a height of 1.72 metres (the average height of participants in the field test). A t-test later confirmed that the height of participants in the field test did not differ from those in the laboratory test (p = .84). A Hitachi CP-SX1350 multimedia projector provided images via an RGB input from a Dell Latitude D610 laptop onto a custom made projection screen (Harkness Screens) measuring 4 x 4 meters. Images were projected onto the screen from a height of 1.1m, 6.8 metres back from the screen at an angle of 10° to avoid the participant blocking the projection. Due to the angled projection, images were keystoned to square to appear natural. The projection screen was designed so that the bottom edge was in contact with the laboratory floor. This meant that the first step of a staircase image began at floor level (see Figure 2). The projected image sizes were then adjusted to match the physical size of the staircase in the field. Since the images were viewed from the same distance away in the laboratory, this was relatively straight forward. Using the dimensions of the first step of each staircase, the image size was increased to match the width and height of the first step, keeping the size of all other aspects of the image relative. While the eye's field of view in the natural environment is roughly 180°, photographs taken 3.6 meters back from a subject with the current camera (focal length 7.1mm) resulted in an angle of view of 103.5°. As Figure 2 shows, the resultant life-sized projections of staircases had less contextual surrounding cues from the periphery than the staircases in the field.

Figure 4.2. A photograph of a participant making a visual matching estimate in the laboratory.

4.3.1.4.2 *Measures and procedure*

Participants were positioned centrally, 3.6 metres back from the projection screen and viewed a blank image until they were ready to start the test. A life-sized projection of either staircase 1 (15.0°) or 2 (18.4°) then appeared on the screen and participants provided geographical slant estimates in the same way as those who had participated in the field test. The screen was then blanked again before participants completed the same test of angle knowledge as participants in the field test. Finally, demographic information (including objectively measured height) was collected before participants were debriefed and reimbursed for their participation.

4.3.1.5 *Data Analysis*

In order to test how similar slant estimates were between the laboratory and in the field we ran a Repeated Measures Analysis of Variance (MANCOVA) which contained three between-subject factors of Condition (Field or Laboratory), Staircase (15° or 18.4°) and Sex (Male or Female), along with a single within-subject factor of Measure (verbal, visual, and haptic). In order to control for participant eye-height, we used height as a proxy and mean-centred measurements within sex. The resultant variable was included as a covariate in all analyses.

4.3.2 *Results*

4.3.2.1 *Participant exclusions*

Participants who failed the angle knowledge test (N=12) were removed from all analyses on the basis that their verbal and visual slant judgements may be unreliable. Of the remaining participants, 5 multivariate outliers were identified and subsequently removed. This left 149 participants (79 male) for analysis. Between-subject groupings of Condition (Field vs. Laboratory) and Staircase (15° vs. 18.4°) remained equivalent for sex, age and height after the removal of these participants (all $p > .65$).

4.3.2.2 *Sensitivity of perception in the field and the laboratory*

The MANCOVA contained a main between-subject effect of Staircase (F (1, 140) = 17.46, $p < .001$, $\eta_p^2 = 0.127$) such that those viewing the steeper staircase (Staircase 2, 18.4°) provided steeper judgements of geographical slant. Crucially, there was no effect of Condition (F (1, 140) = 0.02, $p = .90$, $\eta_p^2 = 0.000$) nor any interaction between Condition and Staircase (F (1, 140) = 0.16 $p = .69$, $\eta_p^2 = 0.001$). As shown by Figure 3, perceptual judgements across the field and laboratory settings were similar on all three measures.

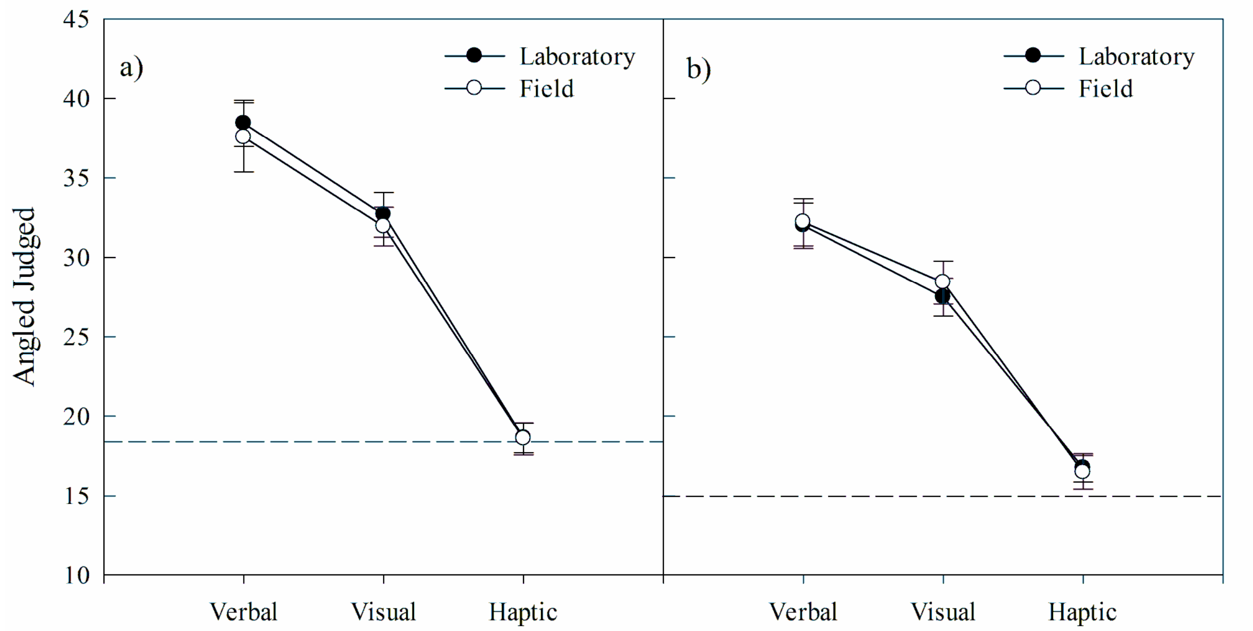

Figure 4.3. Judgements of staircase slant for Staircase 1 (18.4°) (a) and Staircase 2 (15°) (b) by participants in the field and the laboratory settings. The dashed line represents the actual angle of the staircases.

Within-subject analyses revealed a main effect of Measure (F (2, 140) = 246.47, p < .001, η_p^2 = 0.664) which interacted significantly with Staircase (F (2, 140) = 3.59, p < .05, η_p^2 = 0.025), but displayed no interaction with Condition (p = .89). Follow-up independent samples t-tests with Bonferroni correction summarised in Figure 4a revealed that the effect of Staircase was significant for both verbal (t_{147} = 3.57, p < .01) and visual measures (t_{147} = 3.36, p < .01) while an effect on the haptic measure was not statistically reliable after Bonferroni correction (t_{147} = 2.06, p = .12).

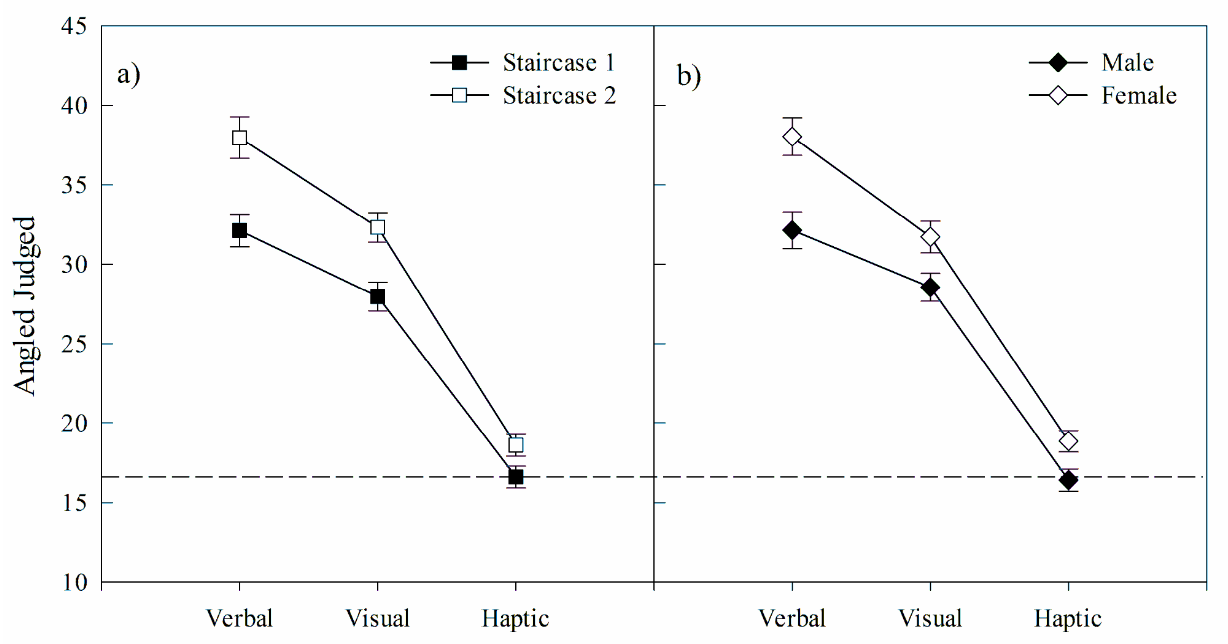

Figure 4.4. Slant judgements from both the laboratory and field conditions by participants viewing either Staircase 1 or 2 (a), and by males and females collapsed across Staircase (b). The dashed line represents the average slope angle of the two staircases (16.7°).

4.3.2.3 *Sex*

The MANCOVA contained a main effect of Sex (F (1, 140) = 20.45, p < .001, η_p^2 = 0.111) such that females provided more exaggerated slant estimates than males. Furthermore, a significant Sex by Measure interaction was present (F (2, 140) = 3.22, p

< .05, $\eta_p^2 = 0.022$). Crucially, there was no three-way interaction between Measure, Condition and Sex ($p > .47$) to suggest differential effects of sex between the laboratory and the field. Follow-up independent samples t-tests with Bonferroni correction revealed that females provided significantly higher slant estimates on verbal ($t_{147} = 3.59$, $p < .01$) and visual ($t_{147} = 2.41$, $p = .05$) measures. To our surprise, females also provided higher haptic estimates than males ($t_{147} = 2.53$, $p < .05$). Inspection of Figure 4b suggests the interaction between Measure and Sex can be explained by the larger magnitude difference between the sexes for verbal estimates (+5.91°) than for visual (+3.16°) and haptic estimates (+2.44°).

4.3.3 *Discussion*

The primary finding of experiment 1 was that geographical slant judgements did not differ between the field and a laboratory setting. Furthermore, estimates for the steeper staircase were more exaggerated, indicating that measures of geographical slant perception was sensitive to a relatively small difference in angle (3.4°) in both environments. Although a significant difference on the haptic measure was not present when applying Bonferroni correction to t-tests, the direction of the difference in haptic estimates between the two staircases is noticeable on inspection of Figure 4a. The fact that mean perceptual differences between the two staircases were larger for explicit measures (verbal and visual) is in line with Proffitt's contention that geographical slant perception conforms to a psychophysical power law. Proffitt and co-workers (1995, 2006) suggest that explicit perception of geographical slant has heightened sensitivity to increases in steepness on shallower slopes. As such, verbal and visual estimates of climbable surfaces increase by a greater proportion of the difference in the slant itself

(Proffitt, 2006, for review). Haptic estimates, however, increase in a more linear fashion (Proffitt et al., 1995).

While participants in the field setting would have had more depth cues at their disposal when judging slant, the result of this experiment suggests that the reduced availability of these cues in the laboratory did not produce different estimates for the two settings. When measuring slant perception using a static image as a stimulus, stereopsis and motion parallax are unavailable to participants. Furthermore, monocular cues such as texture gradients and shading would be less rich due to pixilation of the laboratory image relative to the field. While Feresin & Agostini (2007) reported some loss of accuracy for a 'haptic' measure without binocular disparity in laboratory, participants performed repeated measures for their stimuli, totalling 8 trials for each stimulus. As a result, greater sensitivity to minor differences in angle is likely in the data of Feresin & Agostini (2007). The results of the current study suggest that when participants perform a single judgment of slant, estimates are consistent with those made in the field. We do not suspect that the laboratory setting made other cues available that were not available in the field, but that the life-sized images were of a high enough resolution for the remaining monocular cues to be sufficient in allowing participants to make slant judgements consistent with how they would when viewing the same stimuli in the field.

A potential reason for expecting higher slant estimates in the field setting of the current study is the possible role of intention. Witt et al. (2004, 2010) report that when intentions for throwing or walking a distance are manipulated that verbal estimates of the perceived distance are increased if participants intend to walk to a target. As such, one might have expected steeper estimates of slant in the field condition than the laboratory being that participants recruited in the field were stopped while making a journey that would have included climbing the staircase for which they provided slant estimates. These participants would have higher intentions to climb the staircase relative to participants in the laboratory condition, who could not physically climb the stimuli they judged. Although the current results suggest no role of intention on perceptual judgments of geographical slant, having participants estimate the staircases from 3.6 meters back may have removed any potential effect in this study. It may be that participants need to make judgements for stimuli that start within personal space for effects of intentions to emerge (Wraga et al., 2000).

The current study also showed that females provided more exaggerated estimates of geographical slant than males, an effect that remained robust in the laboratory setting. Although an effect on the haptic measure was not anticipated, one previous study has reported sex differences for the haptic measure with a large sample (Proffitt et al., 1995).

4.4 Experiment 2

Experiment 1 showed that a demographic predictor of behavioural potential (sex) influenced geographical slant perception in a laboratory setting. Experiment 2 tests whether a short-term change in behavioural potential, resulting from depletion of physical resources, would affect perceptual judgements in the same laboratory environment. Previously, fatigue manipulations increased verbal and visual estimates of slant for hills, yet left haptic judgements unchanged (Bhalla & Proffitt 1999; Proffitt et al., 1995). Here, a maximal fitness test was used to induce fatigue. The purpose of the study was partially disguised such that the title given to those taking part was ‘fitness and perception of the built environment.’

4.4.1 *Methods*

4.4.1.1 *Participants*

Physically active undergraduate sport and exercise science students completed the experiment in return for course credit. A total of forty participants (22 male) were randomly split into a fatigued group (11 male, 9 female, average age = 19.83 years, SD=1.58) and a control group (11 male, 9 female, average age = 20.41 years, SD=1.82). Controls provided geographical slant judgements in the laboratory prior to completing the Multi-stage Fitness Test. The fatigued group provided slant judgements immediately after finishing the MSTF, allowing a test of whether the exhausting effect of the maximal fitness test resulted in more exaggerated estimates of geographical slant.

4.4.1.2 *Perception test*

Participants provided verbal, visual and haptic judgements of slant for a life-sized projection of a 2.4 metre high staircase (14.2°) in the laboratory using the same measurement method as in experiment 1.

4.4.1.3 *Multi-stage fitness test.*

First validated by Leger & Lambert (1982), the Multi-Stage Fitness Test (MSFT), also known as the 'bleep test,' is used by sports coaches to estimate a performer's cardiovascular fitness. It involves a progressive 20 meter shuttle run between two points. Each shuttle run must be completed before an upcoming bleep is played over loudspeaker. Across a series of levels, the gap between bleeps decreases, requiring participants to increase their pace in order to keep up. Eventually, the performer is unable to complete a shuttle before a bleep is sounded. In the current experiment, the test area was laid out in a closed off car park adjacent to the laboratory in which perceptual judgements were made.

4.4.1.4 *Procedure*

Participants arrived at a meeting area in the department at a pre-allocated time in same sex groups of three or four to which they had been assigned. Prior to the groups' arrival, experimenters designated them as either an experimental group or a control group. Participants first filled out a General Health Questionnaire to confirm an absence of injuries or illnesses that might affect their performance on the tasks ahead and gave informed consent after reading an information sheet and having the opportunity to ask the experimenters any questions about the research. They then had their height measured before completing the MSFT and perception tests.

For the control condition, participants first completed the perception test, entering the laboratory individually and exiting by a backdoor that led into the car park area once their estimates had been collected. This ensured they could not prime any participants in their group who were yet to provide slant judgements. Once all participants had completed their perception tests and were thoroughly warmed up, they completed the MSFT in their group before completing a warm-down exercise and being debriefed.

The experimental group, after completing questionnaires, were led into the car park area and warmed up ready for the MSFT. Before completing the test, they were shown the backdoor of the perception laboratory and instructed to make their way there immediately after dropping out of the MSFT. As mentioned above, the backdoor of the laboratory opened onto the car park area used for the MSFT, so participants could be in the laboratory ready for their perception test just moments after dropping out of the

MSFT. During testing, one experimenter waited by the backdoor of the laboratory and escorted participants inside to complete their perception tests individually as they dropped out. Two further experimenters administered the MSFT. As the perception tests took about a minute to complete, and the MSFT was run in small groups of 3 or 4 participants at a time, no participant was left waiting to complete their perception test for any significant period after dropping out of the MSFT. Once a participant in the experimental group had completed their perception test, they were led out the main entrance of the laboratory (inside) to a recovery area in order to warm-down.

4.4.1.5 *Statistics*

To test for an effect of fatigue on geographical slant estimates, a Repeated Measures MANCOVA was run which included two between-subject factors of Group (Fatigue vs. Control) and Sex, along with a single within-subject factors of Measure (verbal, visual, haptic). Statistical adjustment for participants' eye-height used the same procedure as experiment 1.

4.4.2 *Results and discussion*

4.4.2.1 *Fatigue*

In line with predictions, a main effect of Group (F (1, 35) = 6.63, p = .01, η_p^2 = 0.159) was present such that fatigued participants gave more exaggerated slant estimates than control participants, as shown in Figure 5a. Within-subject analyses revealed a main effect of Measure (F (2, 34) = 64.97, p < .001, η_p^2 = 0.644), but no significant interaction with Group (F (2, 34) = 0.66, p = .55, η_p^2 = 0.017). Nonetheless, follow-up tests revealed a significant difference between the groups on the verbal and visual measures combined (F (1, 35) = 5.62, p = .02, η_p^2 = 0.138), whereas there was no statistical difference for the haptic measure (p = .24).

4.4.2.2 *Sex.*

As in experiment 1, the MANCOVA contained a main effect of Sex (F (1, 35) = 16.87, p < .001, η_p^2 = 0.325) which interacted with Measure (F (2, 34) = 5.80, p < .01, η_p^2 = 0.142). Follow-up tests revealed that females estimated the staircase as steeper on both the verbal (F (1, 35) = 23.00, p < .001, η_p^2 = 0.397) and visual measures (F (1, 35) = 8.95, p < .01, η_p^2 = 0.204), but not the haptic measure (F (1, 35) = 0.16, p = .69, η_p^2 = 0.005) (Figure 5b). There were no significant interactions involving Group and Sex (all p > .36).

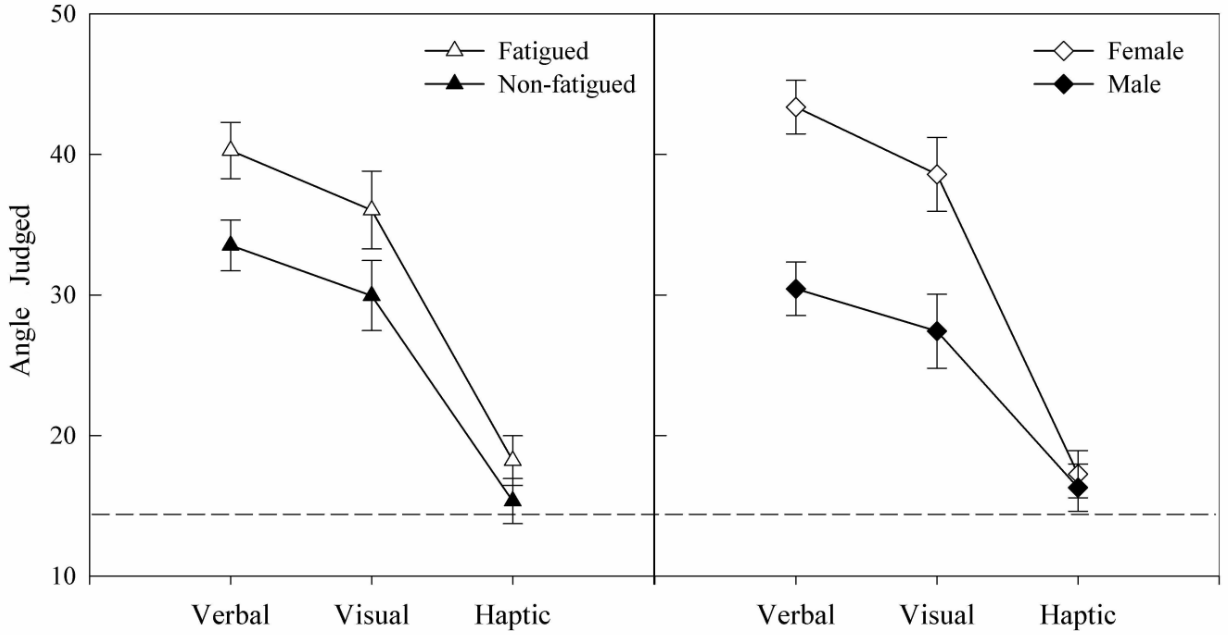

Figure 4.5. Judgements of staircase slant in experiment 2 between Group (a) and Sex (b). The dashed line represents the actual angle of the staircase used as a stimulus.

4.4.2.3 *Discussion*

Results revealed that a fatigue manipulation altered estimates of geographical slant in this laboratory setting, as previously shown for hills in the field. There were no differences between the fatigue and control group in terms of sex, age, height, or fitness (all $p > .30$), leaving fatigue as a primary candidate for observed differences in slant estimates. Bhalla & Proffitt (1999) previously reported an effect of fatigue on estimates of geographical slant, but used a different manipulation which produced a significant interaction between Measure and Group. Our results did not uncover an interaction between Measure and Group, though follow-up tests were consistent with effects of fatigue confined to the verbal and visual measures that Proffitt (2006) links to explicit perception.

4.5 General Discussion

The research presented here suggests that obtained measures of perceived geographical slant using life-sized images of staircases as stimuli can be equivalent to the same measures in the field. In addition, both stable (sex) and unstable (level of fatigue) factors which have been shown previously to influence estimates of geographical slant were shown to do so in a laboratory environment. To our knowledge, this is the first research to show such effects on perceived slant in an easily replicable laboratory setting.

Experiment 2 is the first study to report effects of an experimental manipulation of resources on perceived slant in such a laboratory setting, replicating a result previously found when tested in the field (Bhalla & Proffitt 1999). Nonetheless, an alternative explanation for the observed effects of fatigue in experiment 2 is offered by experimental demand (Durgin et al., 2009). Participants who deduced that the experiment was investigating effects of fatigue on judgements of steepness might have provided more exaggerated reports of slant in line with this expectation. Set against this, participants were recruited to a study about 'fitness and perception,' partially masking the study's aim. While there were no reliable group differences in fitness to explain differences in estimates of slant, without an extensive debrief of participants, we cannot rule out the possibility that demand characteristics influenced judgments.

Previous geographical slant research using virtual reality (Proffitt et al., 1995) found no sex differences on any measure of perception. In addition, a series of experiments investigating perception using a laboratory set-up more comparable to our own, Creem-Regehr et al. (2004) did not report sex differences in any of their four experiments. It possible that with only 20 participants in Proffitt's experiment, and 16 per experiment in Creem-Regehr et al.'s research, that the sample sizes were too small to uncover an effect of sex. As such, the current findings are the first to report that females have more exaggerated perceptions of geographical slant relative to males in a laboratory setting. This suggests that whatever process causes females to report geographical slant as steeper than males is still active when viewing life-sized images of a locomotor challenge. A physiological explanation for this difference is that men carry less dead weight in the form of body fat (Taylor et al., 1997) and have a greater leg strength than to women (Keller, 1989). These physiological advantages make climbing an easier task for males relative to females and offer a potential explanation for the sex differences reported here and in other studies of slant perception (e.g. Proffitt et al., 1995).

In conclusion, the results here with laboratory stimuli open the door to a wide range of future studies where a laboratory setting may be more suitable. The three dependent measures of geographical slant (verbal, visual and haptic) were as sensitive in the laboratory setting as in the field. Future research could make use of similar laboratory based experiments where the physical condition of participants can now be subject to tighter controls when testing for effects of resources on perception of geographical slant.

4.6 Acknowledgements

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CHAPTER 5

Chapter four replicated a previous study that related depleted energy resources to a more exaggerated conscious experience of geographical slant. In light of critiques of such manipulation based between-subject experiments however, further confirmation of this effect was required. In this paper, two quasi-experimental studies were designed to circumvent issues of external validity that deemed prior studies as possibly unreliable.

PAPER 4

WHEN WHAT WE NEED INFLUENCES WHAT WE SEE: CHOICE OF ENERGETIC REPLENISHMENT IS LINKED WITH PERCEIVED STEEPNESS

Taylor-Covill, G. A. H. & Eves, F. F. (under review). *Journal of Experimental Psychology: Human Perception and Performance*

5.0 When what we need influences what we see: Energetic replenishment is linked with perceived steepness

5.1 Abstract

The apparent steepness of the locomotor challenge presented by hills and staircases is overestimated in explicit awareness. Experimental evidence suggests the visual system may rescale our conscious experience of steepness in line with available energy resources. Skeptics of this 'embodied' view argue these findings reflect experimental demand. This paper tested whether perceived steepness was related to resource choices in the built environment. Travelers in a station estimated the slant angle of a 6.45m staircase (23.4°) either before (*N*=302) or after (*N*=109) choosing from a selection of consumable items containing differing levels of energetic resources. Participants unknowingly allocated themselves to a quasi-experimental group based on the energetic resources provided by the item they chose. Consistent with a resource based model, individuals that chose items with a greater energy density, or more rapidly available energy, estimated the staircase as steeper than those opting for items that provided less energetic resources.

5.2 Introduction

The apparent steepness of locomotor challenges, such as hills and staircases, is exaggerated in explicit awareness (Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Shaffer & Flint, 2011). Proffitt et al. (1995) showed that when participants verbally reported the perceived slant of hills, they would typically overestimate a 5° hill to be

20°, and a 10° hill to be 30°. Visual estimates using a disk device to match the slope of the hill were largely consistent with verbal reports. Responses were more accurate, however, when participants adjusted a flat surface to match the slant of hills with their unseen hand, referred to as a 'haptic' measure.

Experimental evidence suggests that an individual's available energy resources directly influences the magnitude of slant overestimation experienced in explicit awareness. Bhalla & Proffitt (1999) found that after encumbering participants with a heavy backpack, or sending them on an exhausting run, verbal and visual measures of perceived hill slant became further elevated, while haptic judgments were unaffected. Proffitt (2006) suggests this sensitivity of explicit perception to fit the resources available to the perceiver may be a functional adaptation that allows more efficient planning of locomotor behavior.

Proffitt's model is not without its critics. Durgin and colleagues (2009, 2012) argue that much of the work supporting Proffitt's model can be put down to artifacts of experimental design, with particular reference to demand characteristics (Orne, 1962). For example, a participant wearing a heavy backpack may 'expect' the hill to look steeper. When participants were given a cover story as to why they were wearing a heavy backpack, verbal estimates of slant were similar to unencumbered participants (Durgin et al., 2009). Furthermore, Shaffer & Flint (2011) reported that verbal overestimations of the slant of a staircase and an escalator were similar, arguing that differences in the potential effort of the climb did not influence perception.

Recent studies of geographical slant perception have used more subtle manipulations that boost, instead of deplete, resources. Participants given a sugary drink prior to making hill judgments provided less exaggerated estimates relative to a group consuming a drink containing artificial sweetner, an effect of blood glucose that provided physiological support for Proffitt's model (Schnall, Zadra & Proffitt, 2010). Durgin et al. (2012), however, have argued that by asking participants to wear a heavy backpack in Schnall's study induced uncontrolled experimental demands. Since blood glucose levels can influence one's ability to regulate self-control (Gailliot et al., 2007), participants receiving a boost in blood glucose may have been more able to *resist* the perceived experimental demands of the backpack, resulting in reduced estimates of hill slant relative to participants in the depleted condition (Durgin et al., 2012). Similarly, Shaffer, McManama, Swank & Durgin (2013) reported that post-experimental reports of susceptibility to the experimental demands of a sugary drink manipulation were a stronger influence on measures of perceived slant than the effects of the drink on energetic resources.

Experimental manipulations of resources will always be susceptible to potential effects of demand. This paper uses a quasi-experimental approach to mask the purpose of the research and minimize the potential effect of demand characteristics. Participants, recruited in a train station, estimated the slant of a staircase, and unknowingly allocated themselves to an experimental group by choosing from food and drink items that differed in the energetic resources provided. When depleted of resources through hunger, falling levels of the hormone 'leptin' lead to a "hungry" brain (Zheng, Lenard, Shin & Berthoud, 2009). In this state, energy rich food stimuli draw increased attention (Piech, Pastorino, & Zald, 2010) and increase activity in the amygdala (Goldstone et al., 2009). These factors make us more likely to choose energy dense foodstuffs from a selection in experimental (Mehta et al., 2012; Page et al., 2011) and consumer contexts (Baumeister, Sparks, Stillman & Vohs, 2007; Wang, Novemsky, Dhar, & Baumeister, 2010). Based on this evidence, we predicted that participants choosing items offering greater levels of energy replenishment would display more exaggerated perceptual reports of slant.

5.3 Experiment 1

In experiment 1, choice of resource replenishment *followed* slant estimates, minimizing the explicit link between the two.

5.3.1 *Methods*

5.3.1.1 *Setting and stimuli*

Testing took place at Snow Hill Station in Birmingham, UK. The stimulus used for perceptual judgments was a 6.45m high staircase leading off the platform (staircase angle=23.4°).

5.3.1.2 *Participants*

Travelers (*N*=302) that appeared of a healthy weight status were recruited while waiting on the station platform and agreed to help with 'an interview about the built environment.' No incentive for participation was offered during recruitment.

5.3.1.3 *Measures and procedure*

All responses were given 3m back from the base of the staircase. Participants provided three estimates of perceived geographical slant; verbal, visual and haptic. The verbal measure involved making a judgment of the 'apparent slant angle of the staircase relative to the ground,' reported in degrees. For the visual measure, participants adjusted a disk device to represent the angle of the staircase in cross-section (see figure 1a). For haptic estimates, participants used a 'Palm-Controlled Inclinometer,' (PCI, Taylor-Covill & Eves, 2013). Participants were instructed to place their hand on the bottom plate of an underslung pendulum and push it forward until it felt as though their palm was in line with the slope of the staircase (see figure 1b).

After providing perceptual measures, participants rated the resource costs of climbing to the top of the staircase on a 10-point scale with the labels; 0= 'no effort,' 5= 'somewhat out of breath by the top,' 10= 'completely exhausted by the top,' were coded for gender, and self-reported their age. This variable was included so that explicit feelings of fatigue or energetic depletion could be controlled for in analyses. If perception is driven by implicit knowledge of available resources, rather than explicit feelings, then effects of resources will still be apparent when this variable is included. To test the reliability of explicit slant estimates, participants were asked to reproduce a 30° angle as accurately as possible using the visual disk device (figure 1a). A 10° range of error was allowed before exclusion.

Figure 5.1. A participant demonstrating use of the visual measure (a) and the PCI (b). The swinging section of the PCI is attached to a set of electronics which displays the angle to which the palm adjusted the swing on an LCD display outside the participants' view.

Following this, participants were presented with a table of fruit and drink items, previously hidden round the side of the staircase (see Figure 2), from which they could "take an item as a thank you for taking part." Unbeknownst to participants, their choice of item determined their experimental grouping. Two types of fruit and two types of drink were on offer to allow for separate comparisons. The two fruit items represented the slow release choices due to longer digestion time and their higher proportion of fructose. Structural differences between sugars means that fructose enters the metabolic pathway for energy at a later stage than glucose (Gropper & Smith, 2012), which accounted for all sugar in the drinks.

The high and low energy, slow release choices were the banana (98kCal) and apple (53kCal), with high and low energy, quick release choices, the Lucozade® drink (140kCal) and Volvic® flavored water (99kCal). After making their choice, participants were asked why they had chosen the item to probe for any explicit bias in choices.

Figure 5.2. Fruit and drinks as presented to participants 'as a thank you for taking part.' Items were displayed in groups of two with different flavors of drinks being made available in an attempt to minimize taste preferences influencing item choice

5.3.1.4 *Analysis*

Participants were excluded if they reported that their choice reflected health issues such as being diabetic or on a diet (*N*=19), or an explicit dislike of any item, e.g. "I hate bananas, so I took the apple" (*N*=42). Further, participants were excluded for failing the test of angle knowledge (*N*=14), or expressing the belief that all staircases were 45° (*N*=6). Boxplots identified a further eight far outliers from the three measures of perception who were removed. The final sample included 213 participants (110 males) between 18 and 72 years of age (*M*=43.2, *SD*=15.2). There were no group differences between those excluded and those retained in the analysis on any of the perceptual measures (all $p>.17$).

Two between subject comparisons of choice were made; Energy Density, that compared the perceptual estimates of those choosing high energy items (Lucozade®, Banana) with those opting for the lower energy alternatives (Volvic®, Apple), and Energy Availability, that compared those choosing fast-release items (drinks) with those who chose slow-release items (fruit). Follow-up analyses included age and perceived resource costs as covariates to control for these factors across different choice groupings. Individuals of increased age have been shown to overestimate hills and staircases more than younger individuals (Bhalla & Proffitt, 1999), while perceived resource costs was included to control for explicit feelings of physical depletion.. Including age as a covariate factored out any age bias in choice of item, while by including perceived resource costs and a covariate cancelled out explicit awareness of depletion affecting item choice. Hence, this analysis can test for implicit awareness of available energetic resources and its influence on choice and perception.

5.3.2 *Results*

5.3.2.1 *Omnibus analysis*

Repeated Measures Analysis of Variance revealed main effects of Energy Density, $F(1, 205)=11.39$, $p<.001$, $\eta_p^2=.053$, Energy Availability, $F(1, 205)=5.73$, $p<.05$, $\eta_p^2=.027$, and Gender, $F(1, 205)=7.85$, $p<.01$, $\eta_p^2=.037$. None of these variables interacted with one another (all $p>.30$). A within-subject effect of Measure (verbal>visual>haptic) was present, $F(2, 205)=256.95$, $p< .001$, $\eta_p^2=.556$, that interacted with Gender, $F(2, 205)=3.58$, $p< .05$, $\eta_p^2=.017$, and Energy Availability, $F(2, 205)=3.80$, $p< .05$, $\eta_p^2=.018$.

5.3.2.2 *Analysis of Covariance*

To test for effects of choice on each measure of perception, a 2 X 2 Multivariate Analyses of Covariance (MANCOVA) was performed with Gender the two choice variables as between-subject factors, and additional covariates of age and perceived resource costs (*M*=3.31, *SD*=2.03). Inspection of the mean perceptual estimates suggest verbal and visual measures represent an exaggerated perception of steepness, while haptic responses were more accurate (Figure 5.3).The MANCOVA revealed that participants choosing items of a higher energy density provided more exaggerated reports of steepness on the verbal, $F(1, 203)=7.87$, $p< .01$, $\eta_p^2=.037$, and visual measures, $F(1, 203)=6.35$, $p< .05$, $\eta_p^2=.030$. Furthermore, participants choosing items offering more rapidly available energy (drinks) estimated the staircase as steeper on the verbal, $F(1, 203)=7.79$, $p< .01$, $\eta_p^2=.037$, and visual measures, $F(1, 203)=4.33$, $p< .05$, $\eta_p^2=.021$. No effects were revealed for the haptic measure (both $p>.39$).

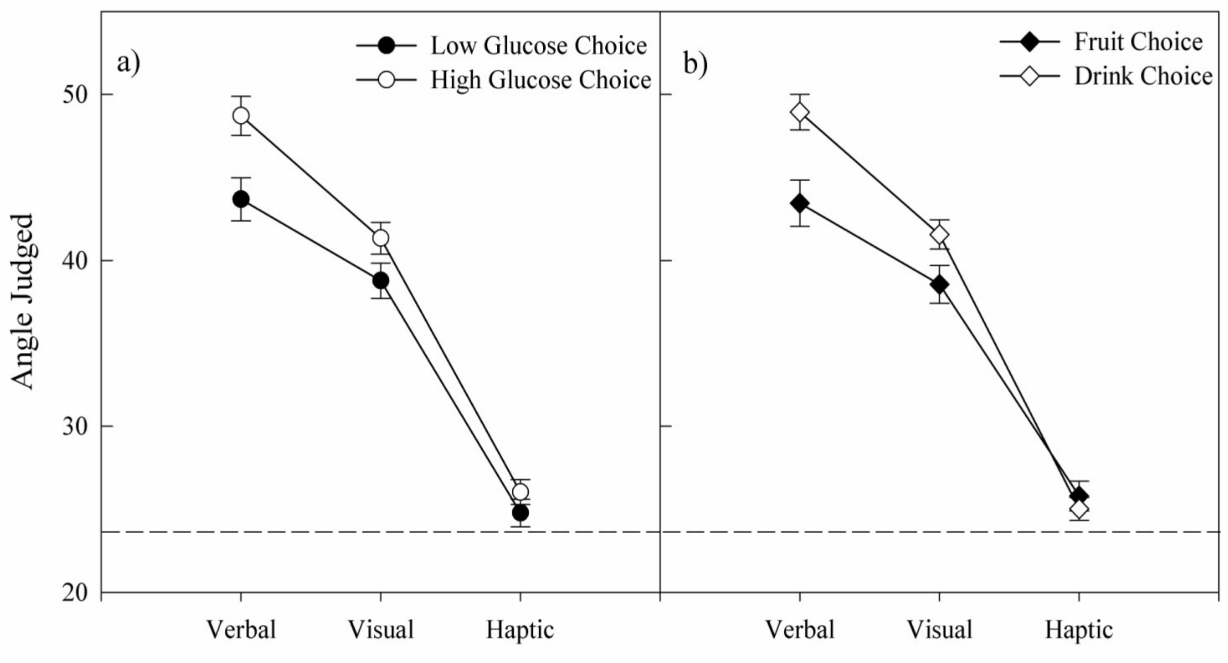

Figure 5.3. Adjusted mean estimates on perceptual measures (±1 *SE*) from experiment 1 showing the energy density choice comparison (a) and energy availability comparison (b). The dashed line represents the overall angle of the staircase.

5.4 Experiment 2

In experiment one, participants who subsequently chose items offering greater energy density, and more rapidly available energy, estimated a staircase as steeper. A possible explanation for this result was that by judging the staircase participants were prompted about their lack of energetic resources, increasing the likelihood that they would select an item offering more potential for energy replenishment. To test this possibility, in experiment 2, the choice between bottles of Lucozade® and Volvic® was made *prio*r to perceptual judgments.

5.4.1 *Methods*

5.4.1.2 *Measures and procedure*

The two drinks featured in experiment 1 were offered to station users upon entry at concourse level 'as a refreshment for their journey,' and designed to look like part of a marketing campaign. Anyone seen holding, but not consuming, one of the drinks on platform level was then approached for recruitment. The measurement procedure was the same as in experiment 1.

5.4.1.2 *Participants*

A total of 109 station users were recruited, of which 32 were excluded due to similar reasons as in experiment 1. A further six were excluded as they reported taking a drink without any intention of consuming it, e.g. "…to give to my son before football practice". The remaining 71 participants (38 male) were between 18 and 65 years of age (*M*=42.1, *SD*=12.4).

5.4.2 *Results*

Repeated Measures Analysis of Variance revealed main effects of Choice, $F(1, 67)=6.54$, $p<.05$, $\eta_p^2=.082$, and Gender, $F(1,67)=9.73$, $p<.01$, $\eta_p^2=.123$, but no interaction between the two ($p>.12$). A main effect of Measure, $F(2,134)=109.36$, $p<.001$, $\eta_p^2=.631$, interacted with Choice, $F(2,134)=4.35$, $p<.05$, $\eta_p^2=.066$, but not Gender. A follow-up MANCOVA employed the same analysis technique as in experiment 1, with the exception that only one choice variable, Energy Density, was included. Results replicated those of the previous experiment (see Figure 4) such that participants who chose the energy rich Lucozade® drink subsequently reported the staircase as steeper on the verbal, $F(1, 65)=8.44$, $p< .01$, $\eta_p^2=.114$, and visual measures, $F(1, 65)=3.04$, $p< .05$, $\eta_p^2=.041$ (one-tailed), with no differences for the haptic measure ($p>.47$). Although a one-tailed *F*-test is not common practice, it was necessary here so that covariates could be included in analysis.

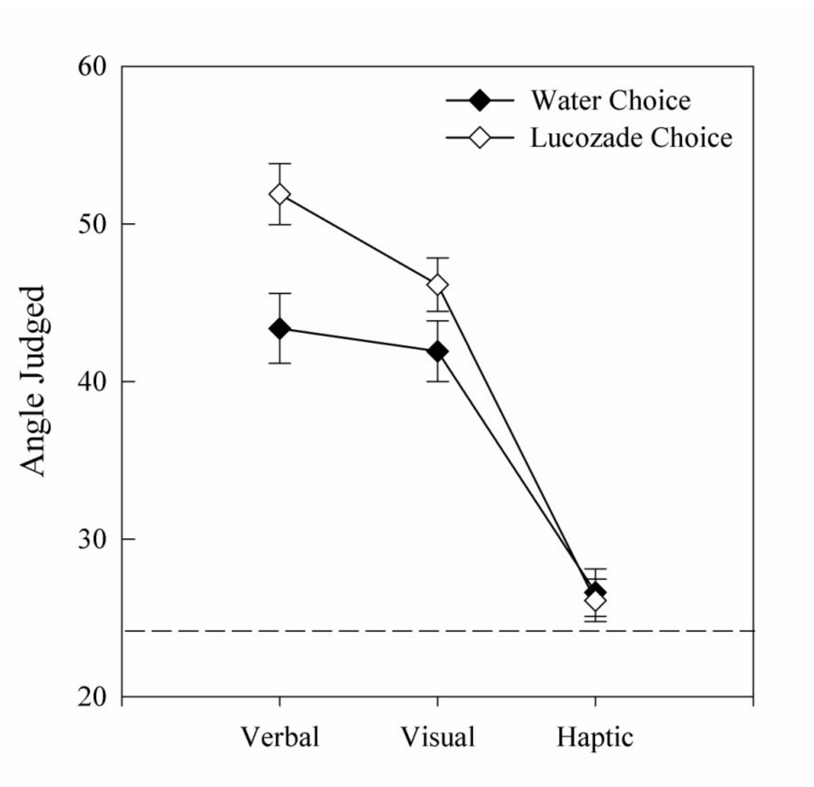

Figure 5.4. Adjusted mean estimates on perceptual measures (±1 *SE*) from experiment 2. The dashed line represents the overall angle of the staircase.

5.4.3 Dis*cussion*

In direct similarity to experiment 1, those opting for the drink more likely to boost energetic resources provided steeper explicit estimates of staircase slant. A null effect of the 'haptic' measure confirmed that available resources only appear to affect explicit perception. This experiment proves that timing of choice does not affect perception, indicating the same process biases food choice and perceived steepness.

5.5 General Discussion

In line with a resource based model of perception, results showed that participants with more exaggerated explicit reports of steepness were more likely to favor fruit or drink items that offered more energy replenishment, while there were no differences uncovered on a 'haptic' measure. Experiment 2 produced a similar pattern of results when the choice of item was made prior to viewing the staircase. In addition, participants with more exaggerated explicit reports of steepness in experiment 1 were more likely to choose items offering more rapidly available energy (drinks). There was no interaction between the two choice variables, suggesting additive effects of energy density and energy availability on explicit perception of steepness.

Our findings are consistent with the predictions of Schnall et al. (2010) and Proffitt's (2006) 'embodied' view of geographical slant perception, supporting a model that suggests energetic depletion biases perception to encourage maintenance of a positive energy balance. The same process that biases choices towards energy-rich foods might also have been in effect when the same participants provided more exaggerated perceptual reports of staircase steepness. We suggest the malleable perceptual bias outlined in Proffitt's model of geographical slant perception might form part of a more global mechanism that fosters energy preservation through visual perception in a variety of ways. By biasing visual attention towards more rewarding food and drink items when depleted of resources, and deterring individuals from energy hungry behaviors such as climbing through an exaggerated perception of steepness, such a process would have obvious survival benefits for any organism if it were modulated by circulating glucose levels.

In both experiments presented here, effects of item choice on explicit measures of perception were robust when analyses included a perceived resource costs variable designed to factor out explicit feelings of depletion. Hence, these experiments provide evidence that group differences in perception might be driven in part by implicit knowledge of available energetic resources. In line with a global mechanism of energy preservation, such a process would be in fit with work that suggests many influences over our dietary decisions take place outside of explicit awareness (Brunstrom, 2004; Seibt, Hafner & Deutsch, 2006). In one example of this form of implicit learning, Zandstra & El-Deredy (2011) showed that participants built up a preference for the more energy dense of two yogurts that only differed by colour labeling. This association of reward from the more energy dense yogurt was built over just a 14 day period. We suggest that the colourful nature of the Lucozade drink affords energy-rich qualities, whereas the clear nature of the flavoured water does not – biasing the choice of those with less available resources to the more energy-rich item. Likewise, the association of bananas with quicker energy than apples could have been built up over years of food consumption being that these two fruits are two of the most commonly sold in the UK.

Research groups that oppose Proffitt's 'embodied' view of geographical slant perception have argued that blood glucose levels only affect perceptual reports when the experimental context induces demand characteristics (Durgin et al., 2012; Shaffer et al., 2013). Experimental approaches to the question will always allow potential effects of demand. The quasi-experimental paradigm used here, however, minimizes these issues. No manipulations were used, nor were backpacks worn. Participants were not taking part for course credit; they were recruited while going about their daily lives and freely chose from the offered items. Although blood glucose was not directly measured, energetic depletion seems the most plausible explanation for our results. Quasi-experimental designs can be interpreted causally if rival alternate explanations can be ruled out (Cook & Campbell, 1979). Participants were probed for the reasons behind their choice of item, with no participant reporting their choice being linked to the steepness of the staircase. Since geographical slant is overestimated universally in explicit reports, a naïve participant would not know whether or not their perceptual estimates were 'normal,' or steeper than average. It seems unlikely that any participant could have deduced that, not only was the choice of food and drink item linked to the measures of perception they provided, but also successfully calculate which item they were expected to select based on their perceptual responses.

In summary, key fundamentals of Proffitt's model of geographical slant perception held up in a quasi-experimental setting that minimized the potential influence of demand characteristics. Our results confirm that explicit reports of perceived steepness are influenced by the available energetic resources of the individual.

5.6 Acknowledgements

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CHAPTER 6

Taken together, chapters four and five present strong evidence for a model that suggests available energy resources affect the extent to which individuals in the built environment overestimate staircase steepness. The paper in this chapter was an initial cross-sectional investigation that relied on self-reports of previous behaviour in order to test the possibility that perceived steepness influenced locomotor behaviour at stair climbing points-of-choice.

PAPER 5

REPORTED STAIR CLIMBING BEHAVIOUR PREDICTS

PERCEPTION OF STEEPNESS

Taylor-Covill, G. A. H. & Eves, F. F. (submitted). *Perception*

6.0 Reported stair climbing behaviour predicts perception of steepness

6.1 Abstract

Perceived steepness of locomotor challenges is exaggerated in conscious awareness. Proffitt (2006) suggests this perceptual bias might help guide our locomotor behaviour towards energy preservation; however, few studies have sought to test a link between steepness perception and behaviour. Here, commuters (*N*=320) reported how often they left a train station platform by climbing a staircase or taking an adjacent escalator, and provided perceptual estimates of staircase in a counterbalanced order. Participants reporting more stair usage provided verbal estimates of staircase slant that were less steep. Our results suggest that perceived steepness is linked with behaviour in this context.

6.2 Article

When stood at the base of a hill or staircase, we report a gross overestimation of steepness in conscious perception; for example, a 5° hill is generally estimated to be about 20° (Proffitt et al 1995). When depleted of energy resources through an exhausting run, or by carrying a heavy load, these perceptual reports become even more exaggerated (Bhalla and Proffitt 1999). Proffitt's economy of action account (2006) suggests that our conscious awareness of steepness is malleable to fit with the resource costs of climbing to the individual. Durgin and colleagues (2009; 2012) disagree, putting the evidence for this model down to influences of experimental demand.

Points-of-choice between a staircase and an escalator provide a context in which steepness perception might directly influence locomotor behaviour. A review of stair climbing literature that coded pedestrian choices between taking a staircase or an adjacent escalator showed that women avoided stair climbing more than men, the elderly more than the young, and the overweight more than slimmer individuals (Eves, in press). In direct similarity, perception studies show that the same demographic groups provide more exaggerated explicit reports of perceived steepness relative to their counterparts (Bhalla and Proffitt 1999; Proffitt et al 1995; Eves et al.; submitted).

Here, we test the relationship between recalls of stair climbing behaviour and perception. In a train station setting, 290 commuters were recruited to take part in ‘an interview about the built environment,’ self-reported their stair climbing frequency at the site, and provided geographical slant perception measures for a large staircase in a counterbalanced order. Participants recalled their frequency of stair climbing a 10-point scale from; 0 - ‘always the escalator,’ to 10 - ‘always the stairs.’ Perceptual judgements were obtained from the base of the stairs. Participants provided a verbal estimate of the slant angle of the staircase in degrees, a visual matching estimate by adjusting a disk device to create a cross-section of the staircase, and a ‘haptic’ estimate using a Palm-Controlled Inclinometer (Taylor-Covill and Eves, 2013). To control for effects of perceived effort, participants rated the personal energetic costs required of them to climb to the top of staircase on a 10-point scale from; 0 - ‘no effort’ to 10 - ‘completely exhausted by the top.’

Demographic factors; sex, age, height and weight, were recorded so that they could be controlled for in analyses. To control for sex differences in perceived effort ratings, height and weight, these variables were mean-centred across sex. Data from 30 participants was excluded prior to analyses; six admitted bias responses in post-experimental questioning, 17 failed a test of angles knowledge, and boxplots identified 7 far outliers across dependent and independent variables. This left 260 participants (145 males) for analysis.

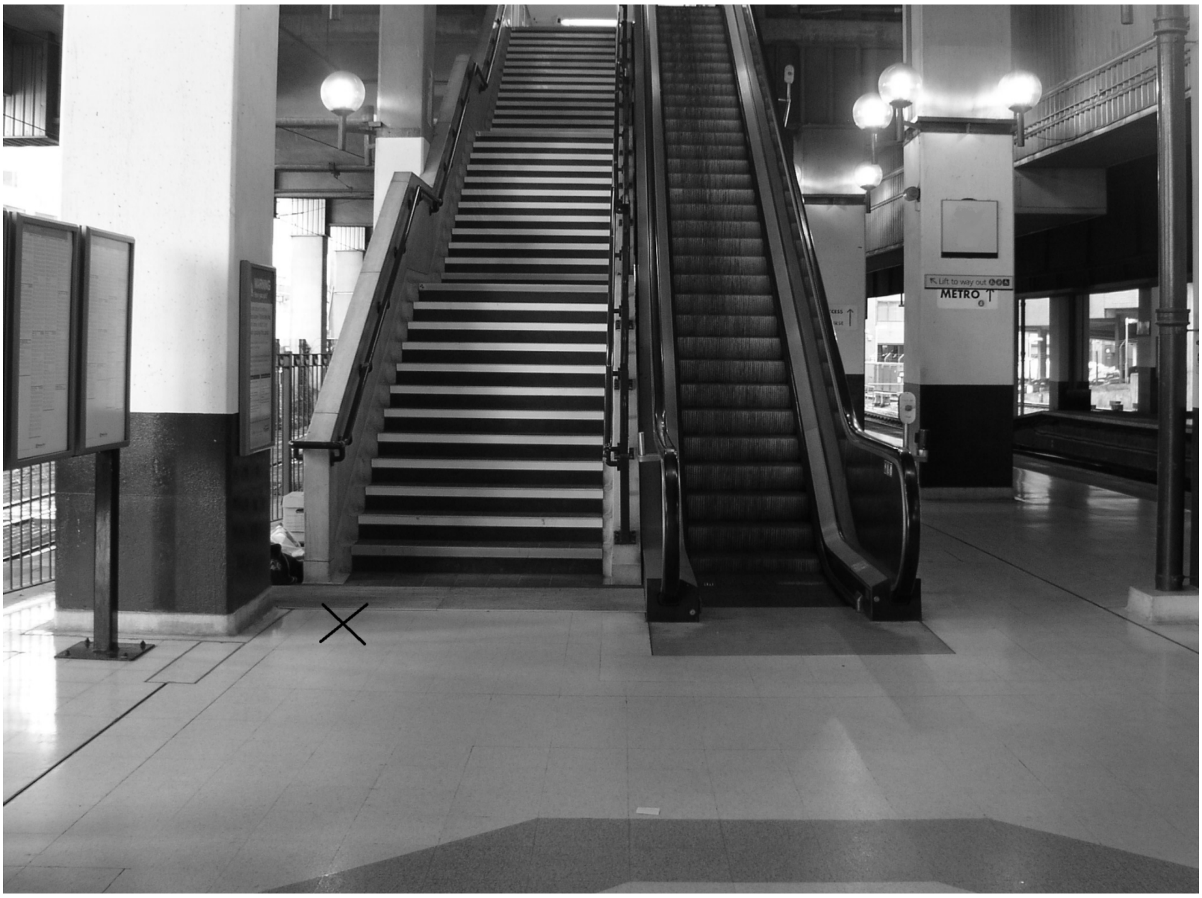

Figure 6.1. A photo of the environment used in the current study taken from the point at which participants judged their stair climbing frequency. X marks the spot where participants provided perceptual measures.

Although Analysis of Variance is the more common analytical procedure in previous studies on geographical slant perception, due to the range of continuous variable data collected here, and large sample size, a regression approach was the used. Multiple Linear regression analyses were conducted with the three slant perception measures as dependent variables. In each model, ‘Reported stair usage,’ ‘Perceived effort (mean-centred),’ ‘Sex,’ ‘Age,’ ‘Height (mean-centred)’ and ‘Weight (mean-centred)' were predictor variables. Only the verbal measure produced a significant model, R^2=.10, F=(6, 254) 4.57, *p* <.001. (Table 6.1). Results showed that the five independent variables predicted 7.8% of the variance with two of these variables having significant contribution to verbal estimates. In line with expectations, commuters reporting less frequent stair climbing over escalator usage provided more exaggerated verbal estimates of steepness (ß= -.147, p <.05). In addition, those reporting more effort for stair climbing provided steeper verbal estimates (ß=.186, p <.01).

Table 6.1. Relative influences on verbal estimates of staircase steepness.

Variable	Coefficient (SE)	95% CI (lower bound-upper bound)	ß	t
Reported stair usage	-0.55 (0.29)	-1.00, -0.10	-.147	2.40*
Female > Male	2.60 (2.27)	-1.88, 7.07	.100	1.14
Age	0.00 (0.52)	-0.10, 0.11	.004	0.06
Height (M-C)	31.92 (30.72)	-28.58, 92.42	.096	1.04
Weight (M-C)	0.00 (0.79)	-0.15, 0.16	.004	0.06
Perceived effort (M-C)	1.22 (0.40)	0.42, 2.01	.186	3.02**

** p <01, ** p <05,* M-C = mean-centred across sex.

Results provide evidence for a link between perceived steepness and reported behaviour in this context. When using an analysis that controlled for independent contributions of each variable, reported stair usage reliably predicted a measure linked to explicit perception. Furthermore, the effect of reported stair usage was significant when perceived effort was controlled for in analysis. This suggests that self-reports were accurate recalls of prior stair climbing behaviour and not simply reflective of the perceived resource costs of stair climbing. While demand characteristics cannot be ruled out as a possible influence on perceptual reports, it should be noted this study took place in the field. Participants were not taking part in research for course credit, they were going about their daily live. Hence, participants here would have unlikely to feel the same level of pressure as those participants involved with traditional experiments.

It remains unclear if climbing stairs more often make them appear less steep, or perceiving stairs as less steep make us more likely climb them. The data presented hear cannot answer this question of causality, but it does provide evidence that our perception of the environment is linked to the locomotor choices we make as part of our daily lives.

6.3 Acknowledgements

We thank the staff of Snow Hill Station, and Devon James, Hannah Brown, Helen Muschamp, and Shelby Sands for their enthusiastic help recruiting and interviewing participants.

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CHAPTER 7

Chapter six presented evidence for a link between explicitly measured perception of staircase steepness and stair avoidance behaviour. This study was limited by the fact physical activity was measured subjectively, which can be an unreliable source of prior behaviour. In order to confirm causality, the study presented in chapter seven was designed to test the effect of perception on stair avoidance behaviour by directly interrupting pedestrians while they were going about a journey. This resulted in an objective measure of choice behaviour that could be correlated with perceptual data. In addition, the paper here tests the influence of viewing distance on perceived geographical slant.

PAPER 6

PERCEIVED STEEPNESS DRIVES HUMAN LOCOMOTOR CHOICES

Taylor-Covill, G. A. H. & Eves, F. F. (submitted).

Psychonomic Bulletin & Review

7.0 Perceived steepness drives human locomotor choices

7.1 Abstract

Research into pedestrian choice behaviour shows females, the elderly, the overweight and individuals carrying heavy bags are less likely than their counterparts to climb a staircase when a less energy intensive alternative, such as an escalator, is available. These findings are in parallel to an existent literature on the perception of steepness. Comparison of results from these distal fields suggests that steepness perception might influence our locomotor choices in the built environment. Here, we directly test this premise in a quasi-experimental study that examined perceptual differences between pedestrians who were about to climb stairs (N=399) and those who were about to avoid stair climbing (N=370). A unique pedestrian site allowed for recruitment of participants before they executed the behaviour, but after making their choice of ascent. Results revealed that those approaching the stairs provided less exaggerated explicit judgements of staircase steepness relative to those avoiding stair climbing. This effect was independent of demographics and viewing distance. The current findings provide direct evidence for a model that suggests perception directly influences our behaviour by informing us of the energy consequences of different locomotor challenges.

7.2 Introduction

According to Tolman's law, we learn through experience to make locomotor choices that lead us towards the routes of travel requiring the least amount of effort in order to reach our goals (Tolman, Ritchie & Kalish, 1946). Such decisions require little conscious deliberation, becoming habitual courses of motion over time (Dijksterhuis & Aarts, 2010). As a requisite for survival, energy output must not outweigh energy intake, hence, any process that might 'teach' us to take the most energy efficient options during natural locomotion would have significant survival benefit.

Energy minimisation is a feature of nearly all locomotor behaviour. Humans naturally adopt different stride patterns for walking (Holt, Hamill, & Andres, 1991; Holt, Jeng, Ratcliffe, & Hamill, 1995) and running (Cavanagh & Williams, 1982) that maximise energy efficiency. Similar patterns of gait change through increasing velocity are seen in other animals such as horses (Hoyt & Taylor, 1981) and insects (Nishii, 2000). When animals climb, they must lift their bodyweight against gravity, making it a particularly energy hungry behaviour. Consistent with this premise, Wall, Douglas-Hamilton, & Vollrath (2006) showed that elephants avoid climbing even when hilly terrain offers significant vegetation on which they could forage. Unsurprisingly, humans also minimise the energy costs of climbing. Minetti (1995) showed that contour maps of ancient footpaths become zig-zag paths at an incline of 14°, an angle of climb which has subsequently been calculated as the optimum gradient for hill ascent in humans. Furthermore, Minetti's work showed that this angle was reduced proportional to the altitude of the path, suggesting our ancestors adjusted their climbing pattern in line with increased physical demands of ascent in more challenging, low-oxygen environments at higher altitudes.

In the built environment, staircases form the man-made equivalent of hills. In a context such as shopping malls, pedestrians are often faced with the choice of climbing stairs, or opting for the energy free alternative of standing on an escalator. Field observations of pedestrian choice behaviour are consistent with an account that suggests we minimise our energy expenditure. Webb & Eves (2007) showed that the rate of pedestrian stair climbing can be as low as 4% when an escalator is adjacent. In this particular example, the staircase consisted of just 15 steps. In line with a model of energy minimisation, demographic groups for whom climbing is a more difficult task in terms of relative energy expenditure, i.e. females, the elderly, the overweight, and pedestrians carrying large bags, all avoid stair climbing more than their counterparts (Eves, in press).

One candidate for deterring stair climbing is our conscious perception of steepness. In experiments where participants are asked to judge the slant angle of hills or staircases, they consistently show a gross overestimation on measures linked to explicit perception. For example, verbal reports of 5° hills are generally around 20°, and visual matching estimates around 15°, while public access staircases (20°-25°) are typically reported to be 45° or over. However, when perception is measured 'haptically' through a motor action with the hand to match the slope of a hill or staircase, responses are more accurate (Proffitt et al, 1995, Taylor-Covill & Eves, 2013a).

The neurological process responsible for manipulating our conscious perception of geographical slant independently from motor processes is unknown. In fitting with a survival model, however, evidence suggests that our available energy resources directly influence the magnitude of slant overestimation consciously experienced. Bhalla & Proffitt (1999) showed that when depleted of locomotor resources through fatigue, participants' verbal and visual estimates of hills became further exaggerated, while ‘haptic’ judgements appeared unaffected. Furthermore, studies consistently show that individuals of a demographic group that have less available resources relative their counterparts, i.e. females, the elderly, the unfit, and the overweight, all display more exaggerated conscious perceptions of hill or staircase steepness (Bhalla & Proffitt, 1999; Eves, Taylor-Covill, & Thorpe, submitted; Proffitt et al., 1995; Taylor-Covill & Eves, 2013b). A link between available resources and perception of steepness might help prevent energy expenditure outweighing energy intake by better informing us about the costs of different locomotor behaviours (Eves, in press; Proffitt 2006).

If such a process influenced human behaviour in the modern, built environment, where energy intake regularly outweighs energy output, it might contribute to the obesity problem by deterring us from freely available bouts of physical activity. A recent review of literature on stair climbing behaviour outlined this possibility, revealing concurrence of demographic differences in pedestrian choice behaviour with those seen in studies of geographical slant perception (Eves, in press). Consistently, across 43 observational studies, women avoided stair climbing more than men, the elderly more than the young, and the overweight more than those of a healthy weight. In direct similarity, women consistently overestimate the steepness of hills and stairs more than men (Proffitt et al., 1995; Eves et al., submitted; Taylor-Covill & Eves, 2013b), the elderly more than the young (Bhalla & Proffitt, 1999; Eves et al., submitted), and the overweight more than those of a healthy weight (Eves et al., submitted; Taylor-Covill & Eves, in prep). Despite the similarity of findings from these distal fields, it is possible that individuals who climb stairs more often, i.e. males, will perceive them as less steep on average due to more experience of ‘overcoming’ the locomotor challenge posed by stairs. This might increase confidence in their ability to climb stairs, which could in turn deflate conscious overestimation of steepness.

Recent data, however, suggest that perceived steepness and stair climbing behaviour are linked. In a study set in a shopping mall, pedestrians were recruited from those who chose the stairs or avoided stair climbing by taking an escalator, with the samples stratified for sex, age and weight status (Eves et al., submitted). Participants estimated the steepness of a life-size image of the staircase they had just encountered, presented on the wall of a vacant shop at the top of the point-of-choice where they were recruited. Those who had just avoided stair climbing by taking the escalator reported the stairs as steeper in verbal reports, even when demographic differences were controlled for. In a further study, regular commuters in a train station reported their stair climbing behaviour on a percentage scale of stair use over escalator use and provided geographical slant perception measures (Taylor-Covill & Eves, submitted-a). Those recalling more frequent stair climbing at the site reported the staircase as less steep, an effect that was independent of demographic influences on perceived steepness and explicitly perceived cost of climbing the stairs.

Despite strong evidence of a link between perception and behaviour, an alternative explanation remains. Successful completion of a behaviour increases one's belief that the behaviour *can* be performed. These beliefs about personal ability, termed self-efficacy, have wide-ranging effects on self-report and behaviour (see Bandura, 1997). For example, self-efficacy predicts participation in physical activity, (e.g. McAuley et al., 2006), performance of lifestyle activities such as stair climbing (e.g. Focht et al., 2005) and self-reported feelings during physical activity (Hu et al., 2007). Development of self-efficacy is a cumulative process; each successful instance of the behaviour improves an individuals' self-efficacy for that behaviour. It is possible that climbing a set of stairs increases ones self-efficacy for climbing that set of stairs, resulting in less steep estimates of the stairs in conscious awareness. To avoid such an interpretation of the relationship between behaviour and perception, here, we recruited pedestrians at a site where the choice to climb stairs was made some 40m before the stairs were encountered. Thus, the choice behaviour was audited before the behaviour itself occurred. In addition, we obtain measures of perceived steepness before the ascent was made.

7.3 Methods

7.3.1 *Setting*

The current study used a unique area in Birmingham city centre where pedestrians chose between a staircase and a sloped walkway in order to make their ascent towards a shopping centre (see Figure 1). Pedestrians make this choice around 40 meters back from the staircase, at the base of the sloped walkway. Those opting to climb the stairs walk across the square before climbing the staircase, while those taking the sloped walkway travel a longer distance, around the square, up a gradual slope that offers a less intensive route up to the shopping centre entrance. Crucially, this site allowed the recruitment of participants before they had attempted to climb either the stairs or slope, but after their choice could be reliably observed (see Figure 1b).

Previous observations at this site revealed that men, those who appeared under 60 years of age and those not carrying heavy bags were more likely to climb the stairs over the sloped walkway than their counterparts (Eves, unpublished observations).

Figure 7.1 a) A photo of the study location taken from the top of the stairs showing the position of recruiters for the slope (x) and stairs (y) and the experimental set-up during ‘close’ condition testing (z).

7.3.2 *Experimental set-up and stimulus*

Experimenters were strategically positioned so that they could recruit pedestrians after they have made their choice of ascent, but before the behaviour has been attempted (see Figure 1b). Participants provided judgements from test stations that were set-up either 5m (close group, Figure 1b) or 34m (far group, Figure 1a) back from the staircase. Chalk markings on the floor of the squared standardised the distance from which participants in each group provided estimates of steepness. The stimulus used for perceptual judgements was the staircase that pedestrians were either approaching, or about to avoid. This measured 4.08 meters high with an overall slant angle of 24.4°.

7.3.3 *Participants.*

In total, 769 members of the public were recruited as participants while walking through the square and spared 5 minutes ‘for a research interview about the built environment for a dissertation project.’ Participants who failed the test of angle knowledge (*N*=60), or expressed the belief that all staircases were 45 degrees in angle (*N*=12), were excluded from analyses. A further eight multivariate outliers were identified during preliminary analysis and removed. The remaining 689 participants (335 male) retained were between 18 and 88 years of age (*M*=39.2, *SD*=16.6).

7.3.4 *Measures, equipment and procedure*

Once recruited, participants were escorted by an experimenter to the field experiment area which was stationed either 5m or 34m back from the staircase (see Figure 1b). They were handed over to either of two experimenters waiting with equipment and data recording equipment to complete their ‘interview.’ Participants were told they would answer a series of questions about how the built environment appears to them and were asked to stand inside footprints that were marked out on the ground with chalk to control participant viewing distance. In line with previous studies of geographical slant, all participants provided three measures of perceived steepness (verbal, visual and haptic). Participants were instructed to look forward at a section of the staircase which had been outlined with chalk to standardise the section of the stairs on which participants based their judgements, and estimate the apparent slope angle in degrees (verbal measure) relative to the horizontal. Participants were then handed a visual disk measure (Figure 2a) and asked to make a visual representation of the cross-section of the staircase by adjusting the dark segment until it matched their perception of the slant (visual measure). For the haptic measure, participants used a Palm-controlled Inclinometer (PCI, Taylor-Covill & Eves, 2013) to judge slope with the hand. Participants placed their right hand on the bottom plate of an underslung pendulum which is hidden from view and were instructed to 'push it forward until it feels like the palm of your hand is in line with the slope of the staircase' (see Figure 2b).

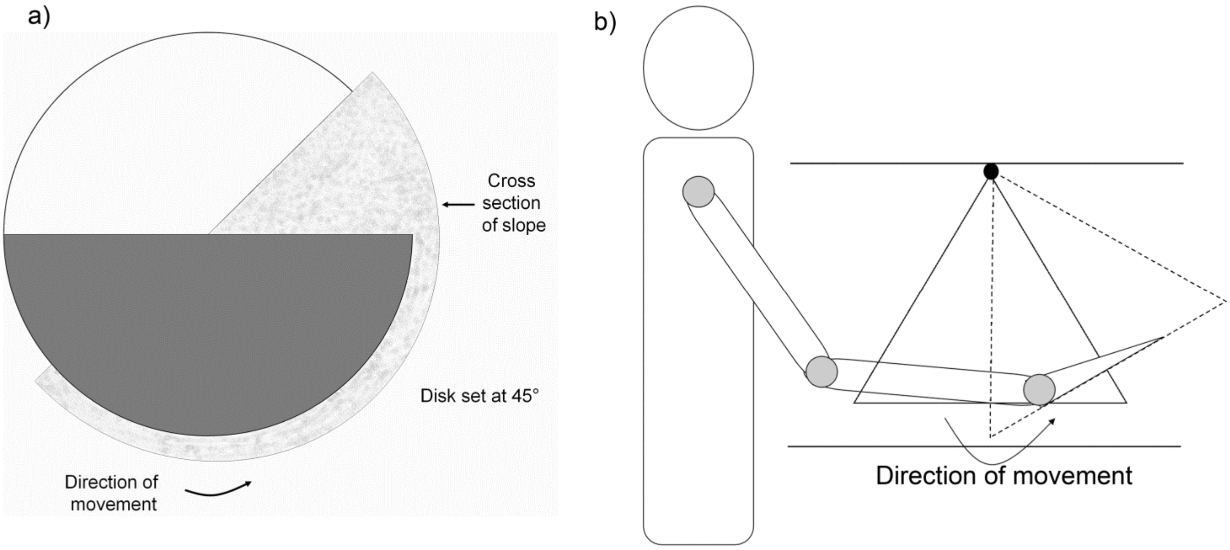

Figure 7.2. a) The disk device used by participants to provide 'visual' estimates of steepness. b) A schematic of a participant using the PCI to provide 'haptic' estimates of steepness. The swing on which participants push has an electronic protractor attached to its pivot which is regulated to display the angle that the bottom plate of the pendulum is being set. This is formulated onto an LCD display, positioned on the side of the device, outside the participants' view.

A further measure was included to test the reliability of participants' verbal and visual judgements. This 'angles knowledge test' required participants to set the visual disk (Figure 2a) to an angle of 30°, participants were instructed to turn around and face away from the staircase while making this judgement. To avoid being excluded from analyses, participants were given an error range of 10°. Finally, participants were asked to provide demographic information regarding their age, gender, height and weight, and sign consent on a separate sheet. On completion, participants were given the opportunity to ask the study co-ordinator any questions they had about the research.

7.4 Results

Repeated Measures Analysis of Variance contained a single within-subject factor of Measure (verbal, visual, haptic), three between-subject factors of Choice (stairs, slope), Distance (base, far), and Sex.

Results revealed main effects of Choice (F (1, 623) = 6.18, p<.05, η_p^2 = .010), and Distance (F (1, 623) = 5.97, p<.05, η_p^2 = .090), but no interaction between the two (p>.94). There was also a main effect of sex such that females provided steeper overall estimates than males F (1, 623) = 20.13, p<.001, η_p^2 = .031). A main effect of Measure (F (2, 622) = 716.52, p<.001, η_p^2 = .697) was present which interacted with Choice (F (2, 622) = 3.31, p<.05, η_p^2 = .011), but did not interact with Distance (p>.44) or Sex (p>.08).

A follow-up Multivariate Analysis of Covariance contained the same within-subject and between-subject factors as the omnibus analysis, but also included covariates of; Age (years), Height (mean-centred across sex), and Weight (mean-centred across sex) to control for demographic influences on perceptual measures. Results presented in Figure 3 show that slope users estimated the staircase as steeper than those choosing the stairs on the verbal (F (1, 620) = 3.85, p < .05, η_p^2 = .006), and visual measures (F (1, 620) = 5.93, p<.05, η_p^2 = .009), but that there were no differences on the haptic measure (p>.89).

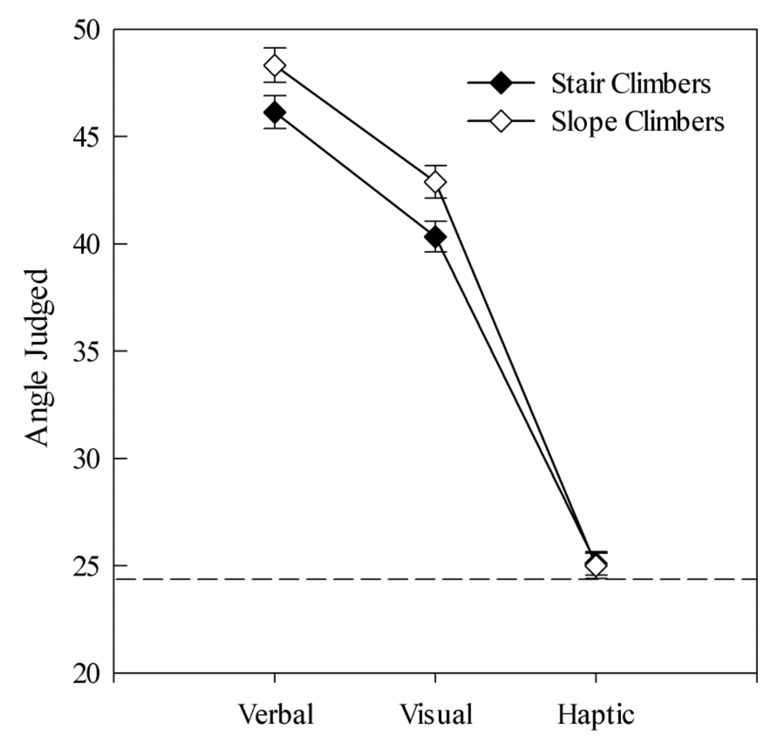

Figure 7.3 Adjusted mean estimates on perceptual measures for stair climbers and stair avoiders. The dashed line represents the overall angle of the staircase.

7.5 Discussion

In summary, recruited pedestrians who were about to avoid climbing a staircase reported it to appear more steep on measures linked to explicit perception than pedestrians approaching the stairs. No such effect was uncovered on the haptic measure, suggesting dissociation between verbal and visual measures, with the haptic one. Furthermore, in replication of previous work, participants judging slant from further back provided steeper perceptual estimates relative to those doing so closer to the stairs (Eves & Thorpe, submitted), and females provided steeper judgements than males (Proffitt et al., 1995; Eves et al., submitted; Taylor-Covill & Eves, 2013b).

Previously, Eves et al. (submitted) showed that pedestrians who *had* climbed stairs subsequently provided less steep verbal estimates of the stairs relative to escalator users. This finding was limited such that participants who had just climbed the stairs may have shown reduced overestimation of steepness due to successful completion of the ascent. In the current study, however, participants had clearly made their choice of ascent clear by approaching either the staircase or slope, but no participant had completed the locomotion associated with the behavioural choice. In addition, the effect of choice remained robust when bodily influences on perception, namely; sex, age, height and weight, were included in analysis.

Our results are consistent with the predictions of a model that proposes perception is governed by an 'economy of action' (Proffitt, 2006). As summarised earlier, when under no external pressure such as time or physical threat, we minimise the energetic costs of our locomotion. This process has little conscious input, suggesting it is phylogenetically old and likely a product of successful adaptation. To ensure energy output does not outweigh energy intake, it is also important we select not only an energy efficient locomotive gait, but that we also select the least energy consuming routes of travel. As such, information about the energy consequences of climbing different paths of ascent to a common destination would be useful. Increased sensitivity to sloped locomotor challenges in our visual perception appears to act as this information source. In the context of foraging, this would be particularly important for survival. Evidence suggests that mammals are particular good at weighing up such locomotor decisions based on the energy costs of ascent against potential for energy gain. For example, elephants avoid climbing hills even when they offer significant vegetation on which they could forage (Wall et al., 2006). It is plausible a similar process of slope avoidance is common across a number of land mammals, and the current research would suggest the medium by which we are deterred from slopes is visually experienced steepness perception. Such a process would have added survival value if it was malleable to fit with our current level of available energetic resources, which is supported by experimental work. Locomotor challenges look steeper when we are fatigued (Bhalla & Proffitt, 1999; Taylor-Covill & Eves, 2013b), or have low blood glucose (Schnall et al., 2010; Taylor-Covill & Eves, submitted-b).

Experimental evidence that supports Proffitt's 'economy of action' account has come under fire for the potential influence of experimental demands on participants in a number of key studies. For example, a participant wearing a heavy backpack in Bhalla & Proffitt's experiment might 'expect' the hill to look steeper and provide increased estimates of slant in line with perceived demand. Durgin et al. (2009) showed that when participants were given a cover story as to why they were wearing a heavy backpack, verbal estimates of slant did not differ from unencumbered participants, suggesting Bhalla & Proffitt's result was driven by experimental design rather than a recalibration of explicit perception. The paradigm used in the current study, however, avoids this issue. No manipulations were used, nor were backpacks worn. Participants were not taking part for course credit; they were recruited while going about their daily lives. Furthermore, since geographical slant is overestimated universally, a naïve participant would not know whether or not their perceptual estimates were 'normal,' or steeper than average. It seems unlikely that any of our participants deduced that, not only was their choice of ascent linked to the perception measures they provided, but also successfully calculate what their perceptual estimates should be based on the locomotor choice they had just made in order to fit with any perceived experimental demands.

The current study provides support for a further model of perception. Evolved navigation theory (ENT) conceives that explicit visual illusions of spatial layout directly affect locomotor behavior, with energy costs, injury risk and time investment all contributing to the magnitude of such illusions (Jackson & Cormack, 2007, 2008;

Jackson & Willey, 2011). In the context used here, time investment might be a factor that would encourage pedestrians to take the stairs, as the sloped walkway affords a longer duration of climb. However, none of the participants included in our perception analysis are likely to have been approaching the stairs for this reason such that they all had time to stop and take part in our study. Injury risk is more likely to influence the behavioral choice of stair descent than ascent. Nonetheless, we ensured debriefing that all participants in the current study *could* climb the stairs. This leaves energetic costs as the primary factor predicted by ENT influencing perceived steepness of participants in the current study.

Although our behavioural-perception data is limited only to the context of stair climbing/avoidance, results provide strong evidence for a model that suggest explicit perception influences behaviour during natural locomotion. The current study provides evidence that our individual perceptual experience of steepness directly influences our decision-making processes during everyday navigation of the environment.

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CHAPTER 8

DISCUSSION AND CONCLUSION

8.0 Discussion and Conclusion

The primary aim of this thesis was to assess the extent to which pedestrian behaviour at stair climbing points-of-choice could be explained by differences in perceived geographical slant. This research took place over a period that saw the development of a heated debate within this field of perception. Proffitt's economy of action model, the premise for predicting that perception might influence pedestrian locomotor choices, was under intense scrutiny. As such, it was also necessary to complete work that approached the testing of Proffitt's economy of action model by new methods to either confirm or deny his account.

8.1 Key Findings

8.1.1 *Perception and Resources*

Studies presented in this thesis confirm the effect of resources on conscious perception of geographical slant. A variety of methods were used that provide new evidence for this aspect of Proffitt's model such that the effect of resources appears to generalise to the perception of stairs, and also is also apparent in a laboratory environment.

In chapter four, experiment two replicated the result of a classic study of fatigue originally presented by Proffitt and colleagues (1995) and later repeated by Bhalla & Proffitt (1999). In a between-subject design, participants who were exhausted estimated the geographical slant of a life-sized projected image of a staircase as steeper than those who were rested. The result showed that manipulations of resources can be carried out in a laboratory setting. Furthermore, this is the first study published to date that demonstrates an effect of depleted resources on perception of geographical slant when staircases are used as stimuli, suggesting Proffitt's model is relevant to the built environment. In the cities of the western world where obesity is prevalent, citizens are more likely to encounter staircases with adjacent energy-saving alternative routes of ascent than the rolling hills used in previous research (e.g. Proffitt et al., 1995). Hence, this study demonstrates that the 'economy of action' account (Proffitt, 2006), which was developed with the perception of hills in mind, is relevant to more recent environmental stimuli. Importantly, this means Proffitt's model might be used to explain demographic differences at stair climbing points-of-choice (Eves, 2013).

In chapter five, a different approach was employed to test the relationship between available resources and perception. In a quasi-experimental field study, participants unknowingly selected their own experimental grouping through the free-choice of food and drink items before or after providing measures of perceived geographical slant for a large staircase. Predictions were based on Schnall, Zadra & Proffitt's work (2010) that showed a manipulation of blood glucose resulted in shallower estimates of geographical slant from participants who had more available energy resources. Proffitt (2006, 2013) contends that circulating blood glucose acts as an individual's 'fuel gauge' to determine the extent of conscious exaggeration of perceived steepness. Behavioural and neuropsychological literature suggests individuals with lower blood glucose are attracted to foodstuffs of a higher energy density, so a choice measure was used as a proxy for available resources. Consistent with Proffitt's model, chapter five showed that those choosing items that offered a boost in energy resources were more likely to have more exaggerated explicit estimates of staircase steepness. Fluctuations in available resources take place throughout our daily lives, so such a process that keeps perception in fit with our 'fuel gauge' has obvious survival value in terms of preserving our energy stores. In addition, evidence from chapter five suggests that implicit knowledge of available resources (circulating blood glucose) directly affects explicit perception. While this has been tentatively conceived by Proffitt (2006) in the past, to date, no study had attempted to test this quasi-experimentally. By including a covariate in analyses that was designed to pick up participants' explicit feelings of depletion through asking them the effort it would take them to climb the staircase stimuli, explicit knowledge of resources is controlled for. In each case, the variable linked to available resources (item choice) remained significantly linked with more exaggerated perceptual reports of steepness. In fit with a survival model, this suggests we are drawn to items that boost our resources when we are not explicitly aware of our energetic resources being low or sub-optimal.

Speculatively, I suggest that this chapter provides evidence for a global mechanism that drives energy preservation through multiple perceptual biases. The robust link between a preference of high-energy and quick-energy-release foodstuffs with more exaggerated perceptual awareness of steepness suggests that the process that drives individuals with lower resources towards more rewarding food items might also drive the perceptual experience of locomotor challenges. I suggest this process is likely modulated by circulating blood glucose, something we are not always explicitly aware of until levels drop to particularly low levels. Proffitt & Linkenauger (2013) refer to circulating glucose as a 'fuel gauge' that governs perception of spatial layout in line with resources, but I suggest this 'fuel gauge' might be in control of a more global process that controls perception not just of the environment around us, but the objects within it, particularly foodstuffs.

8.1.2 *Perception and Behaviour*

In chapters six and seven, two quasi-experimental field studies investigated the link between perceived geographical slant and the consistent pedestrian choice behaviour first presented by Eves (2013). Two separate contexts were used where demographic coding suggests that resources might influence behaviour, a site where pedestrians face a choice between stairs and an escalator (chapter six) and a site where pedestrians face a choice between stairs and a sloped walkway (chapter seven).

Chapter six demonstrated that participants who recalled a higher likelihood of climbing the stairs to exit the train station estimated the staircase as less steep in verbal reports. This effect remained robust in linear regression models that controlled for the influence of demographic and bodily influences on perceived geographical slant, as well as a perceived effort variable. Results linked perception and behaviour in this context, but could not provide evidence for perception driving locomotor behaviour, especially because self-reported physical activity behaviour is problematic (Prince et al., 2008). Chapter seven built on this finding, pedestrian choice behaviour was observed prior to the execution of the associated locomotor action. Results showed that the objective variable of pedestrian choice was significantly correlated with explicit reports of staircase steepness such that those individuals who were about to avoid the stairs reported them as steeper. This finding is important as it circumvents the issue of self-efficacy effecting perception after completing a behaviour associated with perceptual measures. Previously, Eves, Taylor-Covill & Thorpe (under review) showed that pedestrians who *had* climbed stairs reported them as less steep relative to escalator users. Chapter seven suggests that previous finding is not down to an artefact of self-efficacy affecting perceptual reports, but that perceived steepness in conscious awareness *doe*s directly contribute to pedestrian locomotor choices.

Together with the previous work, chapters six and seven provide important behavioural evidence for Proffitt's economy of action account (Proffitt, 2006). In line with the predictions of Proffitt's model, the steeper an individual perceives a locomotor challenge to be, the more likely they are to avoid energy expenditure through climbing.

These results are consistent with a further model of perception, 'evolved navigation theory' (ENT, Jackson, 2011). ENT proposes that the visual system has evolved in order to perceive certain environmental stimuli as illusory in order to preserve energy stores and ensure that perceivers select the safest routes of travel. In my introduction, I discussed conscious geographical slant perception as a naturally occurring visual illusion that might deter energy costly behaviours. In line with both Jackson and Proffitt's accounts, the evidence presented in chapters six and seven supports this notion. Although ENT does not refer to geographical slant perception directly, one could easily speculate that the same system that creates the perceptual illusion of hills and stairs being steeper than they physically are could also be responsible for creating illusions of horizontal and vertical distance presented in Jackson's work. ENT refers not only to energetic costs driving perception of the environment exclusively, but also temporal and falling costs. Time and the risk of falling, however, do not apply to the perception of geographical slant where ascent in the primary objective of the perceiver, as such, Jackson's model might be seen to encompass the 'economy of action' model within it.

When taken in combination with chapters four and five, that demonstrated effects of resources on perception of geographical slant, the work carried out in this thesis suggests available energy resources *directl*y determines our individual level of perceived steepness in conscious awareness. In turn, the level of exaggerated steepness experienced influences locomotor behaviour by biasing individuals with lower resources towards stair avoidance. This suggests that the malleability of perceived geographical slant serves the function of preserving energy in individuals who are depleted of energy resources, a process that may be developed in order to aid survival.

The process I conceive might sound like it comes with obvious advantages to an organism, when blood glucose levels drop, our visual perception becomes increasingly biased towards aspects of the environment that serve to protect energy stores. In our hunter-gatherer past, this might have improved our ability to locate energy-rich natural foods such as berries from a scattered array of branches and leaves on a bush. We might have implicitly understood how far it was worth stalking a potential kill before turning back to the safety of home. In the modernised western world, however, when blood glucose levels are low, this same process makes us more aware of the chocolate bars that surround us in line at the checkout of a supermarket, and divert our attention towards brightly coloured sugary drinks. These foodstuffs typically replenish our energy stores beyond what is needed, leading to a positive energy balance that causes obesity. In addition, low glucose makes the stairs appear more challenging, leading to more time spent standing on an escalator, saving ourselves from a bout of vigorous physical activity that might deplete the energy stored in our muscles, glycogen, in case we need it later. These behaviours, although driven by a process that is critical for survival, contribute to the problem of obesity. For many busy westerners, stair climbing might be the only opportunity for vigorous physical activity encountered during the working week, not only do many need to take on these bouts of exercise to address calorie-balance, but stair climbing, as vigorous activity, has the additional benefit of breaking down glycogen, a process linked to the preventing the onset of diabetes in the obese (Takaishi et al., 2012).

8.1.3 *Accuracy of 'haptic' Geographical Slant Perception*

The focus of chapters two and three was the 'haptic' perception of geographical slant. Although at the start of this project it was not anticipated that such a proportion of the work would be carried out on this aspect of the topic, a heated debate within the literature (Durgin et al., 2010; Proffitt & Zadra, 2011; Durgin, 2011) prompted further investigation. In chapter two, a newly developed device for measuring 'haptic' perception of slant, the Palm-Controlled Inclinometer (PCI), produced generally accurate reports of a range of hills when estimates were taken from the base of the stimuli, in line with Proffitt's contention that perceived geographical slant represents an example of dissociation between perception and action (Proffitt et al., 1995, 2006). Reports that oppose this view, e.g. Durgin et al. (2010), suggested that a lack of available flexion around the wrist joint when using the previously employed 'palm-board' measure resulting in responses that appeared accurate, but might be misrepresentations of true haptic perception. The PCI, however, made extra freedom of movement possible, and although slightly elevated above palm-board estimates, the general accuracy of haptically perceived geographical slant endured. Most importantly, PCI estimates did not differ from the physical angle of slanted stimuli between 20° and 31°, a range in which the majority of public access staircases of interest fall into.

Haptic reports of geographical slant perception were obtained in chapters four, five, six and seven, with results summarised in table 8.1. Haptic judgments did not stray too far from 100% accuracy across the different contexts encountered across these studies. In addition, no experimental variables correlated significantly with haptic estimates of geographical slant, aside from a significant effect of sex in experiment one of chapter four. Based on the data collected in this thesis, 'haptic' perception of geographical slant is both generally accurate and more stable than explicit measures to changes in available resources.

Table 8.1. A summary of average haptic estimates of staircase slant obtained in chapters four, five, six and seven.

	Chapter 4		Chapter 5		Chapter 6	Chapter 7
Experiment	1	2	1	2		
Slant Angle	18.4° / 15°	14.2°	23.4°	23.4°	23.4°	24.4°
Distance from stimuli	3.6m	3.6m	3m	3m	3m	5m / 34m
Accuracy	101% / 114%	118%	105%	106%	107%	100% / 105%

The majority of previous work in this field has measured perceived slant from the base of the stimuli, here, for several reasons, it was necessary to test participants from further back, so distance from stimuli data is included in the table. Bridgeman & Hoover (2008) were the first researchers to present data that showed perceived geographical slant increasing with distance, with Li & Durgin (2010; 2011) later suggesting a linear relationship between the two. The only data from this thesis that can address this question, from chapter seven, is only partially consistent with this account. An increase of average haptic estimates from 24.4° at 5 meters back, to 25.6° at 34 meters back, does not suggest that the effect of viewing distance is as marked as thought by Li & Durgin (2010; 2011), and overall results collected as part of this thesis are certainly not in fit with an account that suggests linearity. It may be that the stimuli used in and Durgin's studies were too far removed from the natural stimuli used throughout this thesis. As discussed in chapter three, haptic perception of slanted objects requires different considerations to that of slant environmental locomotor challenges.

Proffitt et al. (1995) did initially suggest that ‘haptic’ perception of geographical slant represents a dorsal stream process. Although present data cannot confirm the neural basis for the accuracy of haptic reports presented in this thesis, the consistent dissociation from verbal and visual reports of perceived geographical does support Proffitt’s standpoint. Furthermore, effects of demographics and resources are restricted to these explicit measures aside from one instance in chapter four where an effect of sex was uncovered on the haptic measure.

8.1.4 *Demographics*

Chapters four, five, six and seven all measured participant demographics for inclusion in analyses. In all six experiments across presented in these chapters, significant effects of sex were revealed such that females reported stairs as steeper on explicit measures of geographical slant perception. The consistency of this perceptual difference between males and females, even when other demographic and experimental variables were included in the same analyses, provides strong support for Proffitt’s model of geographical slant perception. Although not discussed in depth by Proffitt et al. (1995, 2006), the differences in physiology between men and women are such that sex differences in consciously perceived geographical slant provide compelling evidence for the economy of action account. As reviewed in my introduction, women will on average incur a larger proportion of energy loss to men when climbing a given locomotor challenge. Importantly, no sex differences were uncovered in chapter two, where estimates were made with only haptic measures in a large sample of over 300 participants. Although this provides further support for dissociation between perception and action, it is noteworthy that females overestimated staircase slant on the haptic measure in experiment one of chapter four. This particular example is inconsistent with Proffitt's model, however, effects on haptic measures have been uncovered before in large samples (e.g. Proffitt et al., 1995). A possible explanation is that in some cases, participants' haptic responses are influenced by their prior verbal and visual estimates, having a carry-over effect onto haptic estimates resulting in occasional differences on haptically measured slant geographical slant perception.

The influence of age and bodyweight on perceived slant were not as robust as the influence of sex when measured in chapters five, six and seven. Age only had a significant effect on perceived slant in chapter seven, with a relationship emerging on the visual measure in the expected direction, however, on the other three occasions that age was included in analyses, no significant effects were observed. In the case of bodyweight, when mean-centred across sex and included as a covariate in chapters six and seven, no significant effects were present on any measure of perception. The inconsistency in the relationship between age and perceived steepness was somewhat surprising since age effects have been previously reported in studies that used between-subject comparisons (Bhalla & Proffitt, 1999) and cross-sectional analyses (Eves, Taylor-Covill & Thorpe, under review). Furthermore, based on observational data of stair choice (Eves, 2013) and cross-sectional perception data from a previous study (Eves, Taylor-Covill & Thorpe, under review) it was anticipated that effects of bodyweight might be uncovered. I will now discuss possible explanations for these null findings.

In the case of age, it might be that the effects of sex and additional experimental variables such as effort and choice were too strong for any influence of age on perception to emerge statistically. Data from chapters five and six do, however, show significant effects of age on verbal reports of staircase slant when a different analyitical approach is used. When removing effort variables, and splitting the age variable to compare over 60s with under 60s, creating the same elderly vs. non-elderly comparison used previously by Bhalla & Proffitt (1999), significant effects of age emerge in the data for chapter six, ß=.178, $p<.01$, and in experiment one of chapter five, $F(1, 207)=6.26$, $p<.05$. When applying this method of analysis to bodyweight variables in chapters six and seven, however, no effects emerged. It may be that to uncover effects of bodyweight researchers need to include objective measures of weight as previously used by Eves, Taylor-Covill & Thorpe (under review) rather than self-reports. When asked to report bodyweight as part of a field study, participants are prone to error both due to a lack of knowledge and social pressures (Gorber, Tremblay, Moher & Gorber, 2007). As such, it is possible that the bodyweight data collected in chapters six and seven is not entirely reliable. A number of participants had to be removed from analyses for not supplying this information via self-report. It might be that these participants were representative of the more overweight end of our subject distribution.

Some researchers might perceive the absence of age and bodyweight effects in chapters six and seven as opposing Proffitt's model, however, this viewpoint would be incorrect. Proffitt (2006) contends that one's *individual* level of available resources dictates the extent to which we overestimate geographical slant in conscious awareness. In chapters five, six and seven, where choice and behavioural variables were included, these factors soaked up much of the variance that would otherwise be explained by demographic differences, as exemplified by the example of age presented above. The stratified sampling of demographic groups between the two available choices in chapter seven essentially removed the influence of demographics on perception. This finding is consistent with a previous report that used stratified sampling between stair climbing and escalator usage (Eves, Taylor-Covill & Thorpe, under review).

An additional trend stemming from data presented in this thesis is that the perceiver's height appears relevant to conscious perception of geographical slant. Previous studies in this field have not typically included this metric in analyses, aside from Eves, Taylor-Covill & Thorpe (under review), who uncovered a significant correlation with verbal estimates of staircase slant. In chapters four, five, six and seven, self-reported height, when mean-centred across sex, was consistently correlated with explicit reports of geographical slant in a negative direction. Being taller clearly has some effect in decreasing overestimation of staircase slant. This might be expected in stimuli that are below eye-level, but all stimuli here were well above eye-level, as tall as 6.45 meters in the case of chapters five and six. This finding is important to the field, since previous research on geographical slant perception has not included height in analyses. The results of this thesis highlight the need for the inclusion of participants height data in future works in the field. Although perhaps not as influential as available energy resources, effects of height make sense based on Proffitt's economy of action account (Proffitt, 2006). As noted in chapter one, being taller has its advantages when it comes to stair ascent. The amount of required flexion in the lower limb joints is less for a tall person relative to a short person. Drawing from physiological data (Spanjaard et al., 2007), it is a fair to assume that over the course of a long staircase, shorter individuals will incur a higher proportion of energy loss than taller individuals due to the lesser amount of energy recovery from elastic tissues around the lower leg muscles during climbing. Furthermore, increased height has been shown correlate with maximum lung capacity (Neder, Andreoni, Lerario & Nery, 1999), meaning that taller individuals have more cardiovascular resources on average compared to shorter individuals. Together, these factors suggest that the influence of height on available resources might be an additional factor to consider in the economy of action model.

8.2 Strengths and Limitations

8.2.1 *Research Design*

With the exception of chapter four, the studies presented in this thesis were all of a quasi-experimental nature that involved the recruitment of participants in the field while going about their daily lives.

Experiment two of chapter four, was a between-group design similar to that used in previous studies of geographical slant perception (e.g. Bhalla & Proffitt, 1999). Studies of this design have been criticised for their potential to induce experimental demand characteristics (Durgin et al., 2009; 2012). In my experiment of this kind, participants in the experimental group judged the slant of a staircase image in a laboratory directly after completing an exhaustive fitness test. Control participants, judged the staircase image prior to completing the same fitness test. Durgin and colleagues might argue that participants in the experimental group could have *deduced* that they were expected to provide steeper estimates of staircase slant, leading to more exaggerated explicit reports of slant than were actually being perceived. In an effort to reduce this possibility, the purpose of the experiment was masked by participant information sheets and consent forms being titled ‘fitness and perception.’ Furthermore, the two groups were tested separately, so it is assumed that participants were under the impression they followed the same experimental procedure as others. Nonetheless, it is impossible to rule out the influence of experimental demands in a study such as this entirely because experimenters might still have given off subliminal cues that influence participant responses when collecting measures of perception.

Quasi-experimental approaches to the study of geographical slant pose quite different potential threats to validity. In such cases, experimenters have no control over the prior state of participants. Furthermore, the lack of time with participants meant that control measures such as the Bioenergetics Test Battery (Schnall, Zadra & Proffitt, 2010) could not be administered. As a result, the accuracy of the effect of resources on perception in chapter five, and the effect of perception on behaviour in chapters six and seven, could be improved. Nonetheless, the ecological validity of these studies is unrivalled. For example, in chapter seven, participants were completing a naturally occurring behaviour before being recruited. It seems unlikely that participants in the study could deduce that the choice of ascent they had just made was linked to measures of perception they provided. Likewise, in chapter five no participant expressed during post-experimental questioning any suspicion about the free piece of fruit or drink they were offered. In addition, these studies used public access staircases as stimuli for perceptual judgments. In the context of the modern, built environment, these are the man-made equivalent of hills, and of most relevance to the daily locomotor behaviour of the public that are targeted by public health institutions for interventions that encourage weight maintenance. As such, these studies are the first in this field to speak directly the obesity debate.

8.2.2 *Measurement*

The work completed in this thesis introduced new measures that improve on methodologies employed by previous studies of geographical slant perception. Chapter two introduced a new 'haptic' device, the PCI, that circumvents issues raised with a previous measure, the palm-board. The increased range of motion available with the PCI means that the problem of limited of flexion around the wrist, which had been cited as a potential drawback from use of palm-board for perceiving slant, was resolved.

Furthermore, the action associated with the PCI, pushing forwards to match the palm to a slanted surface, is a better candidate for 'visually guided action' than tilting a board back to match slant with the palm-board, and the housing of the device inside a box set-up means that participants cannot peek at their hand while matching slant. Together, these factors make the PCI more likely to tap into dorsal stream processes of perception that Proffitt cites in his model would be linked to a 'haptic' measure (Proffitt, 2006). As a result, researchers that use this device in the future are in a better position to test dissociations between perception and action in the context of geographical slant.

A further progression in the accuracy of measuring geographical slant perception was presented in chapter four, and used throughout work completed in this thesis that involved explicit measures of perception. The 'angles test' - where participants are turned away from the stimulus at the end of the experimental procedure and instructed to reproduce a 30° angle to the best of their ability on the visual disk device, was used to validate the explicit responses. Without accurate knowledge of the scale with which they use to judge geographical slant, a participant's verbal and visual estimates are unreliable. Although, as one might expect, few subjects from our student sample in chapter four failed the 'angles test,' field studies carried out in chapters five, six and seven showed that public knowledge of explicit angles is far from exact. Across these studies, 11.2% of participants could not reproduce a 30° angle to within 10°. This highlights the potential noise that could contaminate perceptual data when geographical slant research is conducted in the field, and emphasises the importance of such reliability measures in future work.

8.2.3 *Sample Size*

The work throughout this thesis boasts extreme sample sizes for this field. With the exception of experiment two of chapter four, where the sample size was restricted to 40 participants in order to more accurately replicate a Proffitt-style manipulation experiment, participants numbers far exceeded those seen in the majority of previous research on this topic. For example, chapter seven involved 769 participants, a sample size larger than any previously presented in this field.

In the case of the quasi-experimental studies presented in chapters four, five and six, these large sample sizes were perhaps a necessity given the lack of control over the condition of participants. As reviewed in my introduction, such a vast array of factors influence explicit reports of perceived geographical slant that strong statistical power might be required to uncover certain experimental effects while demographics are controlled for. The measures of perception involved are essentially subjective responses rather than direct observations of vision, increasing the need for a large sample. An added advantage of this was the ability to carry out a wider range of statistical analyses such as the linear regression modelling in chapter six that presented independent effects of recalled behaviour, sex, and perceived effort on verbal reports of staircase slant.

8.2.4 *Generalisation of findings*

Recent reports have argued that much of evidence used in support of Proffitt's model has issues of "generalizability" (Durgin et al., 2012). The focus of Durgin's argument is centred on the use of experimental manipulations in previous studies (e.g. Bhalla & Proffitt, 1999; Schnall et al., 2010). Durgin and colleagues contend that effects of resources on perception do not generalise to the natural environment, or our ‘everyday perception,’ and only present themselves under the contextual pressures of a formal experimental. If this were the case, the results obtained in chapters five, six and seven are simply random correlations. Given the consistency of these findings, and the fit of the data with behavioural reports (Eves, 2013) and a previous perceptual-behaviour study (Eves, Taylor-Covill & Thorpe, under review), it seems unlikely that these effects are not driven by perceptual experience.

The field settings used in the majority of research in this thesis presents counter evidence for Durgin and colleagues. Chapters five, six and seven suggest that Proffitt’s model does generalise to our natural, built environment, and to human locomotor behaviour as the economy of action would predict. It is difficult to see how any participant featured in these chapters could have been susceptible to experimental demands. Durgin might still suggest that the social context of these field studies contains uncontrolled social factors such as a tendency to *help* the researcher that recruited them. However, when no manipulation in is in place, and perceived geographical slant is universally overestimated, it is difficult to see how any participant would know *how* to help the research. Furthermore, at no point did any participants express suspicion about their ‘interview about the built environment’ and associated measures during post-experimental questioning.

8.3 Future Directions

The work in this thesis opens to the door to a number of future research pathways. The new methods presented throughout, and the newly validated environment for testing geographical slant perception in chapter four provides the field with a means to test possible influences on perception that might have been previously unattainable.

The largest step forward in the field presented here is that consciously perceived steepness directly influences locomotor choice behaviour (chapters six and seven). Nonetheless, it would be interesting to determine to what extent this perceptual bias is learned through experience, or more hard-wired. The possibility still remains that the tendency to overestimate locomotor challenges predates the behavioural habit of avoiding stair climbing. As such, longitudinal studies with children might shed light on this ‘chicken and the egg’ scenario. This could be addressed by tracking changes in perceived geographical slant, alongside fitness and bodyweight metrics as proxies for available resources, over several years.

Chapters four and five presented evidence that suggests, in line with Bhalla & Proffitt (1999), and Schnall et al. (2010), that one’s level of available resources can effect consciously perceived geographical slant in the short-term. However, no study to date has measured long-term changes in resources against geographical slant perception. This could be achieved by a longitudinal study that monitors changes in fitness and bodyweight alongside perception in adults embarking on fitness improvement and/or weight loss plans to test for the effect of long-term ‘resource boosting’ on perception.

Chapters six and seven showed that the similarities between demographic differences in stair climbing behaviour and perceived geographical slant were no coincidence. As it appears that consciously perceived steepness influences pedestrian choice behaviour, this suggests that other factors known to affect stair climbing behaviour might also affect geographical slant perception. Take for example humidity. Eves & Masters (2006) showed stair avoidance rates increase in high humidity environments. While the authors suggested this was down to a negative affective response to physical activity in high humidity, the evidence presented by this thesis introduces another possible explanation. Perhaps pedestrians *sensed* the increased resource costs of stair climbing in the high humidity environment and this was reflected by a more exaggerated conscious perception of staircase steepness, leading to increased stair avoidance. There are both laboratory based manipulation experiments and quasi-experimental field studies that could be designed to test this possibility.

The consistency and robustness of sex differences on perceived geographical slant uncovered throughout the work presented in this thesis warrants further investigation. A line a research that seeks to disentangle these sex differences would be hugely informative about what aspects that affect resources are most relevant to influencing geographical slant perception. To date, no study has formally controlled for fitness metrics, body composition, muscular strength and bioenergetics in a sample balanced for sex that might determine how these factors interact.

8.4 Conclusion

This thesis set out to determine to what extent embodied perception could be used to explain pedestrian choice behaviour at stair climbing points-of-choice. Chapters two, four and five confirmed the foundations of the economy of action account, and showed that they generalise to the built environment in which pedestrians experience opportunities for stair climbing. Chapters six and seven provide evidence for an expansion of the economy of action account such that available resources not only affect perception, but have a knock on effect of directly influencing human locomotor behaviour. Taken together, the findings presented in this thesis suggest that an embodied model of perceived geographical slant explains both the behavioural tendency to avoid stair climbing when energy-free alternatives are available, and the consistent demographic differences seen in stair choice behaviour. While knowledge of the underlying mechanism that drives this behaviour is informative, the implications for public health and are somewhat bleak. If depletion of energy resources evokes a more exaggerated perceptual experience of staircase steepness, then demographic groups with less resources such as the elderly, the unfit, and the overweight, who *need* to take on such opportunities for physical activity all the more, are the individuals who are more likely to be deterred from stair climbing. A mechanism that alters human visual awareness with the purpose to preserve energy stores is likely the product of successful evolution. It may have ensured the survival of our hunter-gatherer ancestors, however, in the current environment of the western world, it actively contributes to the problem of obesity.

8.5 References

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