Staircases as contextual cues that help minimize energetic costs.

by

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Abstract

Staircase climbs are habitually avoided, and staircase steepness is overestimated. Visual impressions of staircase slant reliably precede each taxing climb and may act as salient, visual cues, prompting behaviour that supports an 'economy of action' (Proffitt, 2006). The thesis adapted the contextual cueing paradigm with natural scenes (cf. Brockmole & Henderson, 2006b) to test for search and learning biases by scene content with staircases. For this, target letters, L and T, were placed near and far from staircases, and in scenes without staircases (three stimulus categories). Eighteen scenes were repeated across blocks, six of each stimulus category. Response latencies and eye movements were recorded.

Chapter three investigated search biases in initial eye movements in response to the first presentation of novel, natural scenes of the three stimulus categories. Findings support the notion that early eye movements were biased towards the incidental scene content of staircases in 36 novel real-world scenes (*N* = 118); this bias was magnified for staircases with more steps, independent of target locations. Chapter two investigated contextual cueing by content of 18 natural scenes, six of each category, repeated across eight blocks (*N* = 64); for 27 of these participants, target locations were changed relative to staircase location in the ninth block. Steeper learning slopes across the eight repetitions were observed for targets located near staircases compared to the other stimulus categories. Interruptions to learning, due to changes in target locations in the ninth block, were a function of the distance to staircase location pre and post changes, consistent with the observed differential learning. Interruptions were equally strong within and between two nine-block learning sessions (*N* = 40) that were separated by a 24-hour break. This additional finding is obtained from a subsequent contextual cueing study, presented in chapter four, and speaks to a major involvement of episodic memory in the learning reported in this thesis. In sum, the findings highlight a capacity of staircase percepts to bias initial visual search, and to facilitate short- and longer-term associative learning near staircases. Overall, the results suggest staircases may be salient stimuli for cognitive processes that manage energetic resources.

Dedication

To Hendrik,

for enthusiasm,

inspiration,

love.

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Onwards as you say, Frank

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Chapter three

List of papers

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

Rosemeyer, M., Jenkinson, N., & Eves, F. F. (2020a). *Where the staircase is and where it wasn't; contextual cueing of visual search by scenes with staircases* [Manuscript submitted for publication]. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham.

Rosemeyer, M., Jenkinson, N., & Eves, F. F. (2020b). *Where the staircase is and how many steps it has; biased search towards staircases when novel* [Manuscript submitted for publication]. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham.

Rosemeyer, M., Jenkinson, N., & Eves, F. F. (2020c). *Where the staircase is and where it wasn't; within- and between-session cueing by scenes with staircases* [Manuscript submitted for publication]. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham.

Chapter one

General Introduction

1 General Introduction

Shoppers prefer waiting on escalators (~1.2 METS) to climbing staircases (~8.0 METS; Ainsworth et al., 2000), but only 92.4% of the time (Eves, 2014; combined *N* = 355,069). This comes at a time when the World Health Organization estimated roughly 40% of adults to be overweight, worldwide (World Health Organization, 2020). It may appear that the shoppers are blind to staircases as easily accessible opportunities for free health care. Indeed, perception may be more relevant than we usually conceive; perceived visual steepness was starkly overestimated for staircases (e.g., Eves et al., 2014) as well as for hills (Proffitt et al., 1995), especially by those pedestrians who avoided climbing them (Eves et al., 2014; Taylor-Covill, 2013). This thesis aims to explore the potential potency of staircase percepts to bias visual search and contextually cued learning in real-world scenes. Developmental learning about costs associated with staircase climbs may have made staircase slant a salient stimulus, efficient in prompting cost-effective, habitual behaviour.

1.1 Associative learning

1.1.1 Habits

I may believe I *chose* to take the escalator, rather than the stairs, when leaving the train station with my wheeled suitcase. But *how many times* have I made *that same choice in the same situation* before? A day later I am on my way to the university, as usual, on my bicycle. How many times have I made *that* choice? Recently, I found this different route to the university, enticing me with unknown visual impressions. Whilst I was clear on my choice to try that route today when I got on my bike, I am off in my head, thinking about the day ahead of me, by the time I approach the critical choice point on my journey. Only after I have automatically turned into the alley, the one I usually take, I realize that I have missed the right turning.

Whenever a specific context becomes predictive of an action, through repetition, such as taking a left turn on my bike at this specific junction, behaviour begins to occur automatically (Oulette & Wood, 1998); automaticity is increased with practice (Lally et al., 2010). This *automated, practised behaviour*, that occurs in response to a *specific context*, is called 'habit' (for reviews see Lally & Gardner, 2013; Wood & Rünger, 2016). The strength of a habit, indexed by the frequency of habitual performance, seems to lie in the *instigation* of behaviour that is then executed mostly automatically (Gardner et al., 2016; Phillips & Gardner, 2016). Staircase slant may be one example of a visual cue prompting habitual behaviour, i.e., avoidance of the climb. As may have become explicit in the above example, strong habits tend to subvert intentions, impeding the implementation of alternative behavioural choices (Danner et al., 2008; Lally & Gardner, 2013; Verplanken et al., 1997).

1.1.2 Development

Habit formation takes time (Lally et al., 2010). In the case of staircases, there is plenty of time to practise, since staircases are experienced and climbed even before we attain the ability to walk upright (Berger et al., 2007). Urban environments provide ample opportunities for rendezvousing with staircases. For example, the city of Pittsburgh, US, offers more than 800 sets of steps, containing more than 45,000 individual steps, to its inhabitants (City of Pittsburgh, 2020). Habitual learning is cue dependent (Orbel & Verplanken, 2010). Perceived staircase slant may provide a stable contextual cue that may be associated with a *felt effort*, approximating the actual energetic expense, through repeated exposure and a lifetime of experiences climbing staircases.

Lifetime, ontogenetic, learning has also been found to be involved in the development of a fear-response towards snakes and threatening objects. DeLoache and LoBue (2009) tested nine-to-10-months-old infants and found no differential responding to films of snakes, compared to films of other animals; in contrast, seven-to-18-months-old infants did react fearfully specifically to snakes. A painful experience associated with a syringe shortened search times for these items compared to pens; items that children had not experienced to be threatening, e.g., knives and spoons, were found in equal time (LoBue, 2010).

1.1.3 Laws of learning & Preparedness

Edward Lee Thorndike was one of the first to suggest that there may be *general laws of learning* (Thorndike, 1901, 1911, 1932, as cited in Derenne, 2019). He suggested that learning generally happens through trial and error. When a certain action leads to a specific satisfying or dissatisfying outcome, a bond, an association, between that action and the response is formed (law of effect). He formulated a number of other laws, amongst them the law of exercise, whereby successful repetition of a stimulus-response effect would strengthen the association; inability to reproduce the response would weaken it (law of exercise).

In 1970, Seligman wrote in his seminal paper ‘on the generality of the laws of learning’ that, contrary to general process learning theory, some learning is biologically *prepared*. The first prominent experiment to show this was performed in 1966 by Garcia and Koelling. Rats were more likely to associate their illness with the *taste* of saccharine-flavoured water than with flashing *light* or *noise*. Seligman (1970, p. 408) proposed a ‘continuum of preparedness’ where biologically likely and relevant associations are ‘prepared’, i.e., more easily formed, compared to other associations. It was said that prepared learning is non-cognitive, specific, quick, and resistant to extinction (Seligman, 1971).

Stimuli that are known to cause phobias, such as snakes, spiders, heights, and closed spaces, can easily be attributed evolutionary significance. Isbell describes in her 2006 paper how snakes may have been instrumental in the forming of the primate brains. Preparedness does, however, depend on experience to be translated into efficient, lifesaving, behaviour. Whilst lab-reared monkeys showed only mild signs of avoidance, intense avoidance behaviour was demonstrated by their wild-reared conspecifics (Joslin et al., 1964). Consistent with the preparedness theory, a fear of snakes was quickly learnt through observation (Cook & Mineka, 1990; Cook et al., 1985; Mineka et al., 1984), whilst a fear of flowers was not learnt under the same conditions (Cook & Mineka, 1987, 1989, 1990). As predicted by the preparedness theory, the acquired fear was still present in a three-month follow-up (Mineka & Cook, 1993). A number of studies revealed enhanced fear conditioning to evolutionarily fear-relevant stimuli, such as snakes, in humans (Öhman, 2009; Öhman et al., 1975), even when there was no time to consciously perceive the predator (Öhman & Soares, 1993, 1994, 1998). More resistance to extinction of learnt responses was observed for these fear-relevant stimuli, compared to all other stimuli (Hugdahl & Kärker, 1981; Öhman et al., 1975, 1976), especially when the conditioned stimulus and the unconditioned stimulus belonged, e.g., an electric shock and the image of a snake (Öhman et al., 1976) and when the threatening animal was facing the participant (Flykt et al., 2007; Hugdahl & Johnsen, 1989).

1.1.4 Dual process theory

Associative learning about staircases, like learning about snakes, is cue dependent. A coiling elongated shape, indicative of a snake, or the 'image of a zigzagging, slanting surface', predictive of a taxing climb, can become a salient cue to cognitive processes, speeding detection (LoBue & DeLoache, 2011) and enabling the initiation of efficient behavioural responses; with practice, these can become habitual.

Dual process theories posit the existence of two interacting processing systems. Associative, cue-dependent learning, as described above, is based on the *impulsive* processing system. Impulsive processes are quick, mostly automatic, and they reduce cognitive effort by forming, cue-dependent, perceptual and behavioural associations. The impulsive processing system is in constant interplay with a slower, *reflective* processing system. Responses formed by this system are based on facts and decisions, for which cognitive capacity is needed (Strack & Deutsch, 2004). An example of the interplay between the two systems offered a study by Sullivan and colleagues (2015) where participants' choice processes for healthy or tasty food were depicted through visualisation of individual mouse movements towards the chosen picture of healthy or tasty food. The authors were able to show that, on average, 'tasty food' influenced the mouse's trajectory 197 milliseconds earlier compared to 'healthy food'. 'Tastiness' of food, comparable to ‘steepness’ of staircase slant, is a property of the food, directly associated with its image. ‘Healthiness’, in contrast, can usually not be directly inferred from the picture, since it is based on facts, on a concept, such as ‘since an apple is a good source of vitamin C, it will be useful for my body’; concepts like this are usually not directly associated with food, they are not experienced.

The *effort* associated with climbing a staircase is a direct, a *felt*, consequence that may be closely associated with the percept of staircase slant in the same way as tastiness is associated with the image of high-calory food, increasing the likelihood for impulsive processing. In the next section, I take a closer look at staircases and associated affordances and costs.

1.2 Staircases

Staircases have been means to reaching different levels of ground for thousands of years. Nowadays, staircases usually afford access to a variety of floors in buildings for living and working purposes. The earliest staircases, however, were built in temples; staircases at that time were only used for the most important issues, such as separating and connecting humans from and with the gods. A very old nine-step staircase, built from blocks of stone, can be seen connecting two temples in the prehistoric Tarxien Temple and Saflienni Hypogeum site in Malta, dating from 3600-2500 BC.

In addition to affording access to higher or lower grounds, staircases also afford free healthcare. Three 20 second bouts of ascending stairs over the course of six weeks led to an increase of 1 MET in cardiorespiratory fitness (Allison et al., 2017; for similar findings see Jakicic et al., 2019, Jenkins et al., 2019, or Kennedy et al., 2007), which is comparable to a 1/7 reduction in the probability of acquiring cardiovascular disease, also lowering all-cause mortality (Kodama et al., 2009). The staircase provides physical step for step guidance and support, however, the person climbing the stairs still needs to raise his or her whole-body weight against gravity on each step. Climbing a staircase takes more than double the amount of metabolic energy (ca. 8.0 - 9.6 METS) compared to level walking at typical preferred walking speed (ca. 3.3 METS; Ainsworth et al., 2000; Teh & Azis, 2002). In addition, modern staircases do not usually include step dimensions that are geared to leg length, increasing climbing costs (Warren, 1984). Furthermore, climbing any slant introduces risks such as injury, fatigue, and hypothermia (Ainslie et al., 2005). The high risks and costs that come with climbing a staircase make it a choice point in the quest of saving limited energetic resources (Levine & Kotz, 2005), a potentially salient cue, relevant for resource-saving, habitual behaviour.

1.2.1 Habitual avoidance

Consistent with the high costs of climbing staircases (8.0 - 9.6 METS) versus resting (1 MET; Ainsworth et al., 2000; Teh & Azis, 2002), 55-80% of commuters leaving a train station (Eves et al., 2008), 64.8% of pedestrians leaving a university campus towards a train station (Ekawati & Eves, 2020), and 92.4% of pedestrians in shopping malls (Eves, 2014; combined *N* = 355,069) avoided climbing a staircase in favour of an adjacent escalator. It has been suggested that time pressure (Eves et al., 2008), crowded escalators, and busy elevators (Olander & Eves, 2011) might increase stair use. Faster walking speeds have been observed on the approach to staircases compared to ramps (Ekawati & Eves, 2020).

Stair avoidance was more prominent for individuals with fewer energetic resources, due to carrying large bags, age, sex, or extra body weight (Ekawati & Eves, 2020; Eves, 2014, 2020; Meyers et al., 1980; see McCardle, Katch, & Katch, 2007 for differences in physiology relevant for climbing staircases in men and women). Higher temperatures were also associated with less stair use (Ekawati & Eves, 2020).

1.2.2 Visual prepotency

Since staircases pose a recurrent threat to limited energetic resources (cf. Ainsworth et al., 2000; Levine & Kotz, 2005; Teh & Azis, 2002) and are habitually avoided where possible (Eves, 2014, 2020; Eves et al., 2014); staircases could be prepotent stimuli. I use the word prepotency to reference a bias that exists prior to any experimental manipulation. This bias can originate from phylogenetic and, or, ontogenetic learning processes (for reviews see LoBue & Rakison 2013; Öhman & Mineka, 2001). To be able to test whether staircases have indeed prepotent properties, a perceptible characteristic of the slanting surfaces must be studied. Images of snakes were readily associated with shock (Öhman et al., 1975) and snake fear was efficiently learnt by visually observing conspecifics behave fearfully around snakes (Cook & Mineka, 1990; Cook et al., 1985; Mineka et al., 1984). For snakes, the typical coiled, elongated shape elicited speeded detection (LoBue & DeLoache, 2011) and differential responding, even when the predator could not be consciously perceived (Öhman & Soares, 1993, 1994, 1998). Vision may be especially relevant when approaching a staircase, since it may be the only accessible source of information on costs associated with the potential climb. As will become explicit in the following sections of this introduction, vision and behaviour are intricately linked.

1.3 Visual perception

1.3.1 How we perceive

Humans have developed sense organs to detect different forms of information. There are scent and taste buds for the detection of chemical substances, the skin as a contact barrier that can detect mechanical energy, pressure, and photoreceptors on the retina that can react to light (Bruce & Green, 1990).

According to the ecological theory, presented by Gibson (1950, 1979, 2002), these sense organs are the place where perception happens. Light is a medium that, whenever it touches a surface, changes and carries information that is revealed in flow and disturbances. Gibson’s ‘direct’ theory of perception states that this is a rich source of information that can be actively sampled in direct relation to bodily metrics and invariants, such as eye height (cf. Warren & Wang, 1987). For example, visually preferred riser height of a staircase step has been found to be directly dependent on leg length. In other words, perception provided direct information on action capabilities in specific circumstances (cf. ‘theory of affordances', Gibson, 1979; Warren, 1984). In Gibson's world, higher cognitive processes are irrelevant, unless optical information is not fully available (Bruce & Green, 1990).

In contrast, constructivist approaches (e.g., Gregory, 1980; going back to von Helmholtz, 1866) describe bottom-up visual information, such as orientation, colour, and intensity as fragmented. Higher cognitive processes, e.g., expectations based on stored knowledge, are needed to make sense of optical impressions (top-down). Perception becomes a process of trial and error, of hypotheses. Gestalt psychologists have formulated Gestalt laws of organisation that assist the grouping of visual features into objects and surfaces (Bruce & Green, 1990).

1.3.2 What we perceive

Visual perception seems to be broad and detailed at the same time. Looking out through a sixth-floor window, I get the impression that I can see wide and far without any obstructions. It seems that my vision allows me to see all there is to see, and that in much detail. It could puzzle me, however, that the little book, sitting on the windowsill, appears to be greater in size than some of the houses in the distance. I cannot see the houses in as much detail as the little book. Clearly, vision is optimized for perceiving and interacting with objects in a certain distance. If people cannot see clearly in that normalized distance, we call them 'farsighted' or 'shortsighted'. Distance limits of vision are apparent as they cannot be compensated for. This is different with focal limits. By moving our eyes, and our focus of gaze, roughly three or four times a second, we create the illusion of a wide detailed field of vision, when, in fact, only a tiny, thumb nail-sized section of what we see is what we can perceive clearly. Whenever we focus our gaze on an object, light is reflected off it and onto our fovea, the part of the retina with the highest number of photoreceptor cells. The quality of visual information generated deteriorates quickly around the centre of the gaze (Land, 2006).

Accurately perceiving small changes in light requires relatively long, 250 ms, periods of stillness (fixations; Hoffman, 1998; Land, 2006), where the gaze stays fixated on one point of interest in the visual surround. Eye movements (saccades) are used to direct and redirect gaze in-between fixations. Research shows that both bottom-up scene features and, for example auditory, top-down information can play a role in guiding our eyes' focus (Buswell, 1935). Bottom-up visual guidance can include more frequent fixations of scene regions with high edge density (Henderson et al., 2009; Mannan et al., 1996), with lines and structures of different orientations (e.g., corners or curves; Krieger et al., 2000), and with high spatial contrast (Reinagel & Zador, 1999). Two exemplary top-down factors that have been found to influence fixation location are episodic scene memory (Loftus & Mackworth, 1978) in interaction with semantic memory (Võ & Wolfe, 2013) and task-related knowledge (Chen & Zelinsky, 2006; Rothkopf et al., 2007; Werner & Thies, 2000). Current studies emphasize the additive nature of top-down and bottom-up information in facilitating visual search performance (Malcolm et al., 2016; Malcolm & Henderson, 2010).

1.4 Perception for action

Gibsonian perception theories suggest that movement plays a central role in perceiving ourselves in relation to the world around us. In moving, we create constant changes in perception (optic flow) that are easily picked up on by our visual system (see section 1.6.3.1 on change detection). This way, vision utilizes changes in the environment that are related to our bodily structure and movement as information on the same (proprioception; Gibson, 2002). Moving-room studies show that infants, who have only just learnt to sit, stand, or walk, tend to sway in sync with their environment, trusting vision more than their bodily signals of stability (e.g., Lee & Aronson, 1974). Similar results were found for young adults when visual information was manipulated (Lee & Lishman, 1975). Vision does not only convey kinaesthetic information independent from mechanical kinaesthesis, it dominates it (Lishman & Lee, 1973). Optic flow provides visual feedback on distance, direction, and speed of movement (Gibson, 1958; Pelah & Barlow, 1996; Prokop et al., 1997; Warren & Hannon, 1988; White et al., 2013). To adjust walking speed, based on perceived optic flow patterns, participants varied step lengths and step durations (François et al., 2011;

Salinas et al., 2017). Similarly, blindfolded participants attempting to march in place moved forward following a 10-minute walk on a treadmill where optic flow translated to zero forward motion. This effect was even stronger after walking on an inclined treadmill (Pelah & Barlow, 1996; Proffitt, 2006; Zadra & Proffitt, 2016).

1.5 Embodied perception

The previous paragraph gives a rough idea of how closely perception and action are linked. Through action, perception is facilitated, and action is adjusted according to perception. More, Proffitt (2006) reasoned that perception of the outside world (e.g., perceived staircase slant) is scaled by the amount of available and task-relevant energetic resources (e.g., leg strength, current baggage) and based on task-relevant energetic affordances and demands of the environment (e.g., a narrow staircase, a slippery surface). In sum, in his view, perception of a specific staircase slant is scaled, in degree depending on an individual's current energetic and action capabilities in relation to this specific staircase, automatically supporting an 'economy of action' (p. 110).

1.5.1 Energetic resources

Energetic costs are minimized in active transport, be it through the adoption of the optimal step width and stride frequency (see Srinivasan, 2009) or through the choice of zigzagging paths that don't exceed a well-climbable slant of 14°. Staircases made up of steps, usually forming a 20-30° slant, on the other hand, are costly; climbing requires two to three times the energetic costs needed for walking on level ground (cf. Ainsworth et al., 2000; Teh & Azis, 2002). In 2006, Proffitt proposed his theory of 'embodied perception for an economy of action' according to which perception is malleable to energetic and morphologic *internal* resources that are relevant for a specific action. Consistent with his account, *geographical slant*, defined as the angle by which the surface of the ground deviates from a horizontal plane (see Gibson & Cornsweet, 1952 for a distinction between 'optical slant' and 'geographical slant'), of hills (Proffitt, 2006; Proffitt et al., 1995, Witt & Proffitt, 2007) and staircases (e.g., Eves et al., 2014; Taylor-Covill, 2013, chapter 7) was overestimated in explicit awareness, such that a hill of 5° appeared as 20° and a staircase of 23.4° was verbally reported as 44.7°. In further support of Proffitt's thesis, and consistent with higher rates of behavioural avoidance (see section 1.2.1), this bias was amplified for participants who were short of resources due to extra body or backpack weight, fatigue, low physical fitness, age, sex, or health (Bhalla & Proffitt, 1999; Eves et al., 2014; Schnall et al., 2010). Conversely, staircase slant was reported less steep when participants were provided with an extra amount of readily available energy; participants, who perceived the staircase as steeper, relative to other participants, were more likely to choose consumables with a greater amount of available energy (Schnall et al., 2010; Taylor-Covill & Eves, 2014). These findings suggest that perceived staircase slant was specifically overestimated compared to the availability of energetic resources.

Similarly, more effort involved in forward motion, e.g., while walking on a treadmill, led to an increase in distance estimation. This was only the case for participants who intended to walk the distance (Rieser et al., 1995; Witt et al., 2004). Distance was also estimated further by participants who carried more weight compared to others (Proffitt et al., 2003; Sugovic et al., 2016). When participants were provided with a glucose drink, compared to an artificially sweetened placebo drink, distances were estimated to be shorter and hills were perceived as shallower (Zadra et al., 2010).

1.5.2 Morphology & Performance

People whose morphology indicates fewer resources relevant for climbing staircases, such as greater body weight or smaller stature, reported steeper staircase estimates compared to others (Eves et al., 2014). A wealth of experiments reported perception scaled by morphology and action capability (e.g., Proffitt & Linkenauger, 2013; Witt, 2011). For example, the perceived size of a graspable object varied relative to perceived hand size (Linkenauger et al., 2013; Linkenauger et al., 2010; Linkenauger et al., 2011). Similarly, perceived distance to a target depended on the participant's ability to reach it, but only when he / she intended to reach it (Osiurak et al., 2012; Witt et al., 2005). Similarly, when bodily and environmental conditions afforded a constant, successful task performance, e.g., in a soft ball game, the relevant object, e.g., the ball, appeared to be bigger. When tennis players played well they reported slower ball movement, and golf holes appeared larger when the task of putting the ball was easier due to skills or current task (Witt et al., 2008; Witt & Proffitt, 2005; Witt & Sugovic, 2010). In summary, targets appear in a size that is related to the current ability of an individual to interact with them.

1.5.3 Threat

The overestimation of perceived staircase slant could also be explained by the heightened risk of injury and predation due to fatigue during and after a climb. Jackson and Willey (2011) found that, when a path included a heightened risk of falling, its length was overestimated in degree relative to the risk of falling (Jackson & Willey, 2011). Distances were estimated to be more than 22-32% farther when viewed from the top, e.g., from a balcony, compared to when they were viewed from the ground (Jackson & Cormack, 2007; Stefanucci & Proffitt, 2009). Participants who were more afraid due to standing on a skate board, a fear of heights, or due to imagining themselves falling from the balcony, reported the distance to the ground as farther compared to other participants (Clerkin et al., 2009; Stefanucci et al., 2008; Teachman et al., 2008).

Spiders appeared to move faster than ladybirds or balls, especially when they were difficult to block (Witt & Sugovic, 2013). A fear of spiders was associated with an increase in perceived size of the animal (Vasey et al., 2012). Both, an aggressive student and a spider, were perceived as closer by and to the participant compared to neutral or disgusting stimuli (Cole et al., 2013); threatening objects appeared closer when they were directed at the participant (Coello et al., 2012).

1.5.4 Other accounts

Previously reported findings seem to suggest that our *perception* of relevant spatial layout, of objects, and of animals in our direct environment is scaled based on effort, bodily dimensions, performance, and potential danger.

An alternative explanation, based on demand characteristics, has been proposed by Durgin and colleagues (Durgin et al., 2009; Durgin et al., 2012; Woods et al., 2009). The authors argued that manipulations, especially of effort, would likely result in response biases, not perceptual biases. A number of other post-perceptual, output-related processes have been suggested to account for embodied perception effects, such as experimenter- and memory-effects. It is possible that an experimenter's knowledge could lead him / her to treat participants differently and so influence a participant's response. It is similarly conceivable that memory could overwrite perception and determine responses (for more details see Philbeck & Witt, 2015).

Whilst post-perceptual effects are a possibility, efforts have been made to preclude these interpretations. One of the ways to guard against response-biases are quasi experimental designs. Using a quasi-experimental design, Taylor-Covill & Eves (2014) found that overestimation of staircase slant was stronger for those participants who chose an edible item that provided more and / or more readily available energy replenishment. This was true for choice of food item prior and post perceptual staircase estimates. In another quasi-experimental study, participants' body composition was measured before and after a weight-loss programme, using Dual X-ray Absorptiometry. Participants with more body-fat at baseline estimated staircases to be steeper. Subsequently, changes in body composition were accompanied by changes in estimated staircase steepness, such that a loss of fat-mass went hand in hand with shallower estimates of staircase steepness. Another way to test for experimenter-effects is to inform participants of the experimental hypothesis. Whether or not participants suspected or knew the aim of the experiment (Witt et al., 2018) and whether or not they received feedback on their performance (King et al., 2018; Laitin et al., 2019) effects on perception stayed the same.

1.6 Staircases as salient percepts

In summary, staircases posit a high risk of expending limited energetic resources, staircase slant is overestimated in explicit awareness, and most people avoid climbing staircases when an alternative is available. Crucially, higher estimates of slant steepness and staircase avoidance have been recorded for those groups of pedestrians, who have a lower availability of relevant energetic resources.

According to Proffitt (2006), the embodied guidance of cognition is an *automated process* that is related specifically to energetic resources necessary for performing a specific action, such as the climbing of a staircase, hereby ensuring that locomotor resources are invested in an energy-efficient and conservative manner. In this automated process, the visual percept of a staircase slant, scaled according to relevant resources (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2014, 2016), may well be a cue that is salient to cognitive processes.

1.6.1 Scene gist

Research on scene gist shows an almost instant recognition and availability of information on scene layout, including broad spatial structures such as streets and staircases (Castelhano & Henderson, 2008). Visual perception of novel natural scenes allows for the following two steps of scene recognition within the first 100 milliseconds. Initially, a scene may be categorized in terms of spatial and functional aspects of scene space (Greene & Oliva, 2009a, 2009b), followed by the perception of scene gist that includes recognition of the basic-category of the scene and some object-level information (Castelhano & Henderson, 2008; Fei-Fei et al., 2007; Oliva, 2005). Even the initial 75 milliseconds of scene recognition can provide information relevant for visual guidance (Castelhano & Henderson, 2007; Võ & Henderson, 2010).

1.6.2 Visual attention

Staircases, as part of scene gist, may be able to influence visual attention within the blink of an eye. Posner (1980; Jonides, 1981) differentiated *voluntary* attention allocation, based on relevant, top-down information and *reflexive* shifts of attention in response to a salient scene feature. He named these processes 'endogenous' and 'exogenous' control of spatial attention (see Carrasco, 2011 for a review). Endogenous shifts of attention take roughly 300 milliseconds for maximum effects, roughly three times as long as exogenous shifts (Cheal & Lyon, 1991) that have been found to happen in a quick and automated manner (see Carretié, 2014 for a review). By definition, exogenous attention is independent of stimulus relevance, as it is often drawn to a cue that is 'uninformative regarding the target location' (Carrasco, 2011, p. 1488); it can interrupt endogenous focussing (Giordano et al., 2009; Müller & Rabbitt, 1989). Long-term perceptual learning was found to be facilitated by exogenous attention, potentially through enhanced stimulus encoding (Donovan et al., 2015; Szpiro & Carrasco, 2015).

Selective attention is highly relevant in an environment that is overcrowded with visual information. Nowadays, the whole marketing industry capitalizes on visual attention. We are given the choice to spend attention, just in the same way as money, to view specific content 'watch one more ad'. Innately we all know that we want our children, our parents, our friends to be attentive when we tell them something that is of import to us. Research agrees with our learnt behaviour: What we attend to can be processed in more detail (e.g., Prinzmetal et al., 1986) and we are able to respond quicker and more accurately (Egly et al., 1994; Henderson, 1991).

Shifts in eye-movements occur roughly four times per second (Rayner & Castelhano, 2007) and attention shifts potentially much more often without visible changes (Liversedge & Findlay, 2000). Overt, attention allocation, visible through eye movements, has been found to be closely related to covert, invisible, attentional shifts (Deubel & Schneider, 1996; Henderson, 1992), such that quick, covert attention seemed to precede and prepare overt, saccadic shifts (e.g., Godijn & Theeuwes, 2003; Henderson et al., 1989; Hoffman, 1998; Peterson et al., 2004).

Rapid and early shifts of attention can be signs of exogenous attention control (Posner, 1980; Jonides, 1981). In the following paragraphs I will look at attentional biases that may be based mainly on exogenous shifts of attention and that may also be present in the perception of staircase slant.

1.6.3 Attentional biases

1.6.3.1 Change

It is impossible not to notice the person opposite me change appearance. Right?! Research suggests that this is indeed very possible, even when I am in the midst of an active conversation with that person when the change happens. In the specific experiment, one experimenter, referred to as 'conversation partner', started a conversation with a pedestrian. 10 to 15 seconds into the conversation, two other experimenters carried a door through between the two speakers, briefly blocking the view of the conversation partner. Unseen to the pedestrian, the conversation partner was replaced by one of the other experimenters. Only half of the pedestrians reported noticing the change (Simons & Levin, 1998). Implicit change detection may differ from consciously reported detection (cf. Williams & Simons, 2000). In the above experiment, change detection rates were higher for participants who belonged to the same age group as their conversation partner (Simons & Levin, 1998). Research revealed that the change movement itself is an important signal that can draw attention (cf. optic flow, section 1.4). Whenever we miss that signal, change may not be detected even if it seems blatantly obvious afterwards (cf. Simons & Rensink, 2005, see also movement for threat detection in DeLoache & LoBue, 2009). This phenomenon is called 'change blindness'. It has been suggested that change blindness occurs due to a fragile initial representation of a scene (Levin et al., 2002; Rensink et al., 2000; Ward & Scholl, 2015) or potentially due to a missing comparison of pre- and post-change scenes (Angelone et al., 2003). Conscious change detection lives on attention (e.g., Rensink et al., 1997; Scholl, 2000) and on fixations near the target (Henderson & Hollingworth, 1999; Henderson et al., 2003; Hollingworth et al., 2001). Change detection is more successful within a known social group (Simons & Levin, 1998) and for objects that appear to be important within a scene (Rensink et al., 1997). Attention seems to be necessary, but not always sufficient for conscious change detection. Even changes to directly attended objects can stay undetected (Triesch et al., 2003; Simons & Levin, 1998).

Movement is one cue that alerts us to change, to novelty (e.g., Hacklaender et al., 2015). According to the model proposed by Scherer (2001), any detection of novelty is followed up with a schematic comparison involving previous knowledge and a relevance check. All this needs to happen rather quickly if appropriate action is to be taken in time. As may become apparent in the following sections, this usually involves exogenous, rapid shifts of attention to the relevant visual stimulus.

1.6.3.2 Novelty

Any novel stimulus will draw attention because of its potential relevance to survival. Novel stimuli can be ones not encountered before, 'stimulus novelty', and familiar ones that are novel within a specific context, 'contextual novelty' (Schomaker & Meeter, 2015, p. 269). Within experimental contexts, 'category novelty' is commonly employed, for example with groupings of different pleasant and unpleasant stimuli into categories.

One of the first people to notice and document the effects of novelty was Pavlov, at the beginning of the 20th century. Pavlov (1927) was astonished when his dogs repeatedly seemed to forget their conditioned responses in the presence of strangers. He finally concluded that a 'What-is-it?' reflex outweighed the trained responses. This reflexive, exogenous, orientation towards novel stimuli became later known as 'orienting response' (Bernstein, 1969; Donchin, 1981; Graham, 1979; Graham & Clifton, 1966; Öhman, 1979; Siddle & Spinks, 1979; Sokolov, 1963). Orienting has been described as a range of responses typically elicited by novel stimuli, including arousal, exploratory behaviour, a focussing of attention, a heightened sensitivity, and enhanced learning (Donchin, 1981; Mayer et al., 2011; Öhman, 1979; Schomaker & Meeter, 2012, 2015; Siddle, 1991; Sokolov, 1963). One primary sign of orienting, noted by Pavlov already in 1927, is a reflexive, exogenous, aligning of the eyes with the novel stimulus. This is efficient exploratory behaviour, since eye movements usually occur before any manual response (e.g., Bannerman et al., 2009). As will become apparent in the following sections, reflexive orienting of visual attention has recently been demonstrated for a number of salient stimuli; I believe it may also be relevant to the potentially salient percept of staircase slant that poses a threat to metabolic resources.

1.6.3.3 Threat

Using the change-detection paradigm, New and co-workers (2007) found that changes in humans and animals were detected more frequently (*M* = 89.8%, *SD* = 7.4%) and quicker (*M* = 3034 ms, *SD* = 882 ms) than changes in plants, or inanimate objects (*M* = 64.9%, *SD* = 15.7%; *M* = 4772 ms, *SD* = 1404 ms).

Quick and accurate detection of small changes in human faces can reveal feelings and intentions that may be relevant to survival. Angry faces may be examples of threatening stimuli. From an evolutionary perspective, falling out with somebody important could lead to the exclusion from all family and village life. This threat may be reflected in a quicker and a more accurate detection of angry compared to friendly, sad, or scheming faces (Öhman, Lundqvist, & Esteves, 2001). This anger superiority effect has been found especially for target faces that were male and familiar (Öhman et al., 2010). Accurate detection of angry, versus neutral, faces was also advantaged when display duration was limited to 150 milliseconds, suggesting an early automatic component (Calvo et al., 2006), as in an orienting response.

Detecting and responding to animals may be especially relevant in an encounter with a threatening animal, such as a snake. For one, it may be important to determine quickly whether it actually is a snake, or just a shadow on a branch. The speed of detection and recognition translates into the likelihood of defence and escape. When observers were shown images of snakes, spiders, lions, flowers, and mushrooms, it was the threatening animals that were fixated (LoBue et al., 2014; Rosa et al., 2011) and responded to sooner (LoBue et al., 2014), resulting in quicker and more accurate detection of these stimuli (LoBue et al., 2014; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001; Soares et al., 2009; Yorzinski et al., 2014). More efficient search for threatening than for non-threatening targets may be based on parallel, compared to serial, search processes (Blanchette, 2006; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001). In addition to capturing attention sooner, dangerous animals and contexts also held attention for longer, even when they were mere distractors (cf. Carrasco, 2011 on exogenous attention; Harris et al., 2008; Yorzinski et al., 2014).

More, research in paired scenes designs repeatedly revealed a bias of even the first saccade towards emotionally salient scenes, compared to neutral ones, (Calvo & Lang, 2004; Calvo et al., 2008; Fernández-Martin et al., 2017; Nummenmaa et al., 2006, 2009). This attentional capture was evident in overt and covert attentional orienting even when the emotional stimuli were task-irrelevant (Fernández-Martín et al., 2017; Nummenmaa et al., 2009; see Carretié, 2014 for a review), consistent with an involvement of exogenous attention (cf. review by Carrasco, 2011).

1.6.3.4 Relevance

Novel and threatening stimuli have one thing in common: a potential *relevance* for the survival of the organism. This commonality can also explain attentional biases related to *modern* threatening objects, such as guns, knives, and syringes (Blanchette, 2006; Brosch & Sharma, 2005; Flykt et al., 2007; Fox et al., 2007). The so-called ‘*threat*-superiority effect’ has since been reconsidered as a potential ‘*relevance*-superiority effect’ (Fox et al., 2007; Sander et al., 2003). Consistent with a *relevance*-superiority, research confirmed earlier fixation of *relevant positive* stimuli, comparable to what was found for threatening stimuli; examples of relevant positive stimuli include food (De Oca & Black, 2013; Sawada et al., 2019; Sawada et al., 2017) and baby faces (Brosch et al., 2008; Brosch et al., 2007; see Pool et al., 2016 for a meta-analysis). The relevance effect was found especially for stimuli that are relevant to *survival* (cf. *law of concern*, Frijda, 1988), such as stimuli related to nourishment, reproduction, and offspring (see Pool et al., 2016 for a meta-analysis on attentional bias for positive emotional stimuli). Stimulus relevance can also depend on the current state of an individual (cf. *law of situational meaning* and *law of apparent reality*, Frijda, 1988), such that calorific food was detected more rapidly, compared to low-fat food, only by those participants who had fasted prior to participation (Sawada et al., 2019).

In summary, *attention* allocation is not arbitrary; subjectively relevant stimuli, more than neutral stimuli, elicited exogenous shifts of attention towards their location; these attentional shifts enable speeded detection and have been associated with enhanced target memory.

Staircases may be examples of relevant stimuli since they present a recurrent threat to energetic resources (e.g., Teh & Azis, 2002), whilst simultaneously rewarding the climber with a boost to cardiorespiratory fitness (e.g., Allison et al., 2017). Literature suggests that rewarded stimuli (Failing & Theeuwes, 2014; Pool et al., 2014), and threatening stimuli (e.g., LoBue et al., 2014; Nummenmaa et al., 2009), may capture early attention, and facilitate associative learning, even without conscious perception of the stimuli (cf. Öhman & Soares, 1993, 1994, 1998). Staircase slant, a threat to energetic resources, may have prepotent properties, attracting initial eye movements (cf. Fernández-Martin et al., 2017; Jonides, 1981; Nummenmaa et al., 2009; Posner, 1980) and increasing the likelihood of associative learning (cf. Cook & Mineka, 1989; Öhman et al., 1975), whilst resisting extinction of learnt associations (cf. Hugdahl & Kärker, 1981; Öhman et al., 1975, 1976). Speeded detection would afford an early activation of associations, e.g. feelings of effort, (cf. Strack & Deutsch, 2004) and efficient behavioural responses.

To find out more about the visual saliency of staircase slope, we deployed a visual search task with real-world scenes that included staircases as incidental scene content. Previous research conducted by Taylor-Covill and Eves (2013, 2016; Eves et al., 2014) revealed equal degrees of overestimations of staircase slant whether a participant was facing an image of a staircase or its physical counterpart. Would proximity to an incidental staircase, compared to other built environment, such as houses, within a scene, facilitate search and learning of nearby scene content? Would initial eye movements be reflexively biased towards the image of a staircase within a scene?

1.7 The contextual cueing paradigm

In our experimental studies we adapted the contextual cueing paradigm (Chun & Jiang, 1998) with real-world scenes (cf. Brockmole & Henderson, 2006a, 2006b) to test for biased learning of target positions near to and far from staircases, that formed part of the global scene context.

1.7.1 Contextually cued learning

In contextual cueing, a visual search target appears in a consistent location within a repeated context. Repeated target-context configurations enable increasing precision in cueing by context towards the target location, detectable in progressively efficient eye movements (Manginelli & Pollmann, 2009; Sisk et al., 2019) and a shortening of response latencies (e.g., Chun & Jiang, 1998; Brockmole & Henderson, 2006a, 2006b), compared to search in novel scenes. The contextual cueing effect has been reported from research with visual search arrays of letters and shapes (e.g., Chun & Jiang, 1998) as well as with real-world scenes (see Brockmole and Henderson, 2006a, 2006b; Wolfe et al., 2011). Contextual cueing was more rapid (Brockmole et al., 2006; Brockmole & Henderson, 2006a, 2006b; Henderson, 2017), more explicit (Brockmole & Henderson, 2006b), and more pronounced in natural scenes, compared to learning in abstract letter arrays, (Castelhano et al., 2019). We aimed to explore whether and how contextually cued learning would be biased by the presence of incidental scene content that includes a staircase.

1.7.2 Strength of learnt associations

The strength of learnt target-context associations can be evaluated through a change in target locations. In letter arrays, relocating targets typically led to a stark increase in response latencies (Becker & Rasmussen, 2008; Makovski & Jiang, 2010; Mangenelli & Pollmann, 2009), followed by a slow relearning process of the new target locations in the array (e.g., Zellin et al., 2014). To our knowledge, no studies have been conducted on target relocation and re-learning *in real-world scenes*. We know that real-world scenes and letter arrays differ in a number of ways, such as in their complexity and in meaning (Goujon et al., 2012), in memory formation (e.g., Brockmole & Henderson, 2006b; Chun & Jiang, 1998), in the use of local and global context for referencing target location in contextual cueing (e.g., Brady & Chun, 2007; Brockmole & Henderson, 2006a), and in magnitude of the contextual cueing effect (Castelhano et al., 2019; see also Jiang & Sisk, 2019 for a comparison between array-based and scene-based contextual cueing).

1.7.3 Memory in contextual cueing

Both, *semantic* and *episodic* memory are said to support visual search in repeated scenes, their relative contribution may depend on available information (Brockmole & Võ, 2010; Goujon, 2011; Hollingworth, 2012; Võ & Wolfe, 2013). It has been claimed that semantic information may not be strictly necessary for explicit contextually cued learning, however, it has proven useful in adapting to changes in visual stimuli (Goujon et al., 2012).

Semantic memory, as defined by Tulving (1972, as cited in Renoult & Rugg, 2020, p. 2), stores ‘organized knowledge’ about the world, including general visual, functional, and spatial object knowledge, e.g., pillows are usually angular and located in living- and bedrooms. Whilst semantic memory is based on comprehension, episodic memory is based on personal reliving, on sensations that are associated with a specific remembered event. Rather than the retrieval of general facts, episodic memory allows the reconstruction of scenes that are spatially and temporally structured from the viewpoint of a ‘self’ (Tulving, 1984). In other words, episodic memory allows for the retrieval of ‘personally experienced unique events’

(Tulving, as cited in Renoult & Rugg, 2020, p. 2; see Tulving, 2002 for a brief history of episodic memory). This could be my personal memory of my seventh's birthday celebration, in the living room of my parents' place, when my mum handed me a doll she had made for me.

As a more recent refinement, Rubin and Umanath (2015) suggested *event memory* to form the basis for episodic retrieval. Three characteristic ways in which it differs from episodic memory may make it especially relevant for more abstract memories, such as memories from a contextual cueing task in a laboratory setting. For one, rather than needing to be about the self, event memories are scenes reconstructed based on a viewpoint that can be first or third person, one that can vary. Second, the authors argued that the sense of reliving is not a necessary determinant of event memory, they discussed 'reliving' as a product of judging a recalled scene. Third, recall does not need to be voluntary. Event memory, the deconstruction of memories into separate events, was also mentioned as a key component of habit formation (see Judah et al., 2013).

In summary, we believe that images of staircase slant may be automatically associated with a felt effort, accrued through prior experiences of climbing similar staircases. This learning may have made staircase percepts prepotent stimuli, salient to cognitive processes, eliciting exogenous attention and facilitating associative learning even within scenes.

In the literature, scenes were memorized within a second (Standing et al., 1970) and scene and object information were retained over hours, in some detail (e.g., Brady et al., 2008); visual memory was maintained across 2912 intervening trials even with more than 60 images of the same category (Konkle et al., 2010). Consistent with these findings, memory for repeated, real-world scenes in contextual cueing was almost perfect, 97%, and the error in target localisation small, only 1.7 cm (Brockmole & Henderson, 2006b). Indeed, research on visual memory capacity is astounding; immediately after studying 612 pictures, participants were able to recognize 96.7% of them and memories were retained across testing sessions. 7 days later, recognition rates were still around 87%, higher than for different forms of verbal material (Shepard, 1967; for similar results see e.g., Hollingworth, 2005; Standing, 1973; Standing et al., 1970).

Contextual cueing with real-world scenes has been found to produce strong cueing effects, which we expect will be biased by scene content that includes a staircase; stronger memory of target-context associations near the salient scene feature of staircase slant may interfere with efficient remapping following changes in target positioning.

1.8 The experimental chapters

The following three paragraphs are included for a brief overview over aims of the three experimental chapters (chapters two, three, and four) presented in this thesis.

1.8.1 Chapter two

The second chapter aims to replicate contextual cueing with real-world scenes, based on research by Brockmole and Henderson (2006b). Additionally, we want to test whether staircases, as incidental scene content, can enhance cued learning of proximal target locations, whilst hindering cueing towards locations elsewhere in the scene. If this was the case, we would expect associations between target and context to be stronger near staircases. This will be tested via a change in target locations relative to staircase location in the final block of stimulus presentation. If target-context associations were stronger near staircases, it is conceivable that targets relocated farther from staircases would be associated with a greater increase in search times, whilst weaker target-context associations might be more adaptable to change.

1.8.2 Chapter three

The third chapter of this thesis explores a potential prepotency of staircases in natural scenes (for our definition of prepotency see section 1.2.2). We believe staircases may become prepotent stimuli primarily through ontogenetic learning processes. If this were the case, already the first presentation of a novel staircase scene could reveal exogenous attention shifts towards staircase slant, comparable to findings previously reported in relevance detection (see sections following 1.6.3). In this study, eye movements are tracked. We are especially interested in the first block of novel stimuli and in the direction of the first meaningful saccade relative to the location of task-irrelevant staircases that provide part of the global scene content. Staircases are included in the spatial scene layout, the scene gist (e.g., Oliva, 2005), with the potential to bias search immediately upon scene presentation.

1.8.3 Chapter four

The fourth chapter is concerned more specifically with the learning processes observed in chapter two; learning rates of similar and more distinct stimuli are contrasted.

Whilst memory performance is high, even with images from the same category (Konkle et al., 2010), and semantic relatedness can aid memory in certain circumstances (O'Donnell et al., 2018), it has been suggested that relative stimulus uniqueness can also facilitate explicit memory formation (Diamantopoulou et al., 2011; Goujon et al., 2012). Consistent with this claim, similarity of target and distractor scenes has been found to reduce and even eliminate scene memory (Melcher & Murphy, 2011).

In addition, the study includes a second learning session, separated from the first session by a 24hr gap. To find out more about episodic memory contribution in contextually cued learning, we compare the strength of learnt target-context associations within- and between learning sessions.

1.9 Literature

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Chapter two

My first experimental chapter presents findings from two response time contextual cueing experiments that were used as a filler task in a study testing for effects of resources on the perception of pictures of hills and staircases. Half of the participants had omitted breakfast, fasted participants, and half had had breakfast and received a snack bar at the beginning of the testing session, sated participants. The response time experiments served the purpose of ensuring that the snack bar would be fully consumed and registered by sated participants' bodies. Unknown to participants, both experiments aimed to test for potentially biased search by staircase slants that were included in real-world contextual cueing environments. Biased learning, benefitting target locations near staircases compared to locations far from staircases, as well as a stronger resistance to re-orienting search to changed target locations more remote from staircases, relative to positions relocated nearer to staircases, were our predictions. Response times in the control condition were expected to be intermediate.

Paper 1

Where the staircase is and where it wasn't;
contextual cueing of visual search by scenes with staircases

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2 *Where the staircase is and where it wasn't;*

contextual cueing of visual search by scenes with staircases

2.1 Abstract

Introduction. Climbing stairs is an energetically costly locomotor behaviour and staircases are relevant stimuli for cognitive processes that manage locomotor resources.

Objectives. This paper explores the potential for biased learning benefitting content proximal to staircase location in real-world scenes.

Methods. Using a contextual cueing paradigm, participants (*N* = 120) searched novel and repeated real-world scenes for targets that were placed near a staircase, far from a staircase, or in a scene with a building and without a staircase. The staircases were presented face-on in the scenes. In the first experiment, nine blocks of 18 repeated scenes were employed whereas the second experiment changed target locations in the ninth block to test the strength of learnt target-context associations.

Results. Consistent with previous research, target locations that remained constant within scenes across repetitions, were associated with steeper learning curves compared to target locations in novel scenes. In repeated trials, target locations near staircases were learnt more rapidly than those far from staircases and those in scenes without staircases. In the second experiment, targets moved away from the staircase were disadvantaged relative to control scenes, whereas targets moved closer were at an advantage. The least disruption for target relocation nearer to a staircase provides triangulation on this evidence of biased search revealed by learning slopes.

Conclusions. These findings support the notion of search being biased towards the location of staircases in real-world scenes. Discussion focuses on differences from the original research on contextual cueing and the potential prepotency of staircases in real-world scenes.

2.2 Introduction

Habits are behaviours associated with contexts (Lally et al., 2010; Orbell & Verplanken, 2010; Oulette & Wood, 1998; Wood & Rünger, 2016). Typically, pedestrians, navigating a context that contains stairs, avoid climbing them when there is an alternative means of ascent (Eves, 2014, 2020). This avoidance is a habit linked to contexts that can be disrupted by health promotion messages (Eves & Puig-Ribera, 2019; Kerr et al., 2001; Lewis & Eves, 2012; Webb & Eves, 2007). Increased use of stairs in the built environment is a current target of public health (e.g., Physical Activity Guidelines Advisory Committee [PAGAC], 2018). Nonetheless, habitual avoidance of stairs to conserve energetic resources runs counter to these public health efforts (Eves, 2020). Perception of the stairs within a climbing context is important; pedestrians who avoid the stairs report them as steeper than those who climb them (Eves et al., 2014; Taylor-Covill, 2013, chapter 7). Staircases are environmental stimuli, salient about function, that are relevant to cognitive processes that manage energetic resources.

One major issue for humans is energy balance; expenditure greater than intake cannot be sustained. Two thirds of an adult's energy intake are required for basal metabolic functions and food breakdown (Levine & Kotz, 2005); these are unavoidable recurrent costs of daily life. Only about a third of daily intake is available for all bodily movement that day; walking may account for 89% of these movements (Levine & Kotz, 2005). The characteristic bipedal gait of humans requires continuous work against gravity as the centre of mass rises and falls during each step (Alexander, 2002; Croft et al., 2017). Adults automatically adopt a step width, step length and step frequency that minimise the metabolic cost of walking (Srinivasan, 2009), with the visual consequences of locomotion used to calibrate behaviour towards optimal (Pelah & Barlow, 1996; Rieser et al., 1995; Srinivasan 2009; White et al., 2013; Zadra & Proffitt, 2016). This calibration occurs in real-time (Prokop et al., 1997; Selinger et al., 2015). Control of locomotor cost is a functional adaptation required for bipedal walking.

When toddlers learn to walk upright, they complete on average 2,368 steps and suffer 17 falls per hour (Adolph et al., 2012). Typically, toddlers explore their environment extensively, rambling 'throughout the room' (Adolph et al., 2012, p. 5). This experience allows toddlers to acquire a functional bipedal gait while undergoing morphological changes associated with maturation. With practice, progressive increases in step length and decreases in step width begin to approximate the regularity of the adult gait pattern that minimises costs (Adolph & Hoch, 2019; Vereijken et al., 2009). When stability is threatened by carrying additional weight, toddlers successfully adapt their gait (Garciaguirre et al., 2007; Vereijken et al., 2009) and alter their choice of behaviour at downhill slopes (Adolph & Avolio, 2000). Bipedal gait is a malleable, purposeful skill, even in toddlers. Extensive learning during development delivers the functional skill that conserves resources in adulthood.

Climbing, the behaviour avoided in stair contexts, is associated with almost a tripling of metabolic cost relative to purposeful walking on level ground (Ainsworth et al., 2000; Teh & Aziz, 2002). Raising all of one's body weight against gravity is costly, 9.6 times more so than sitting (Teh & Aziz, 2002). As a result, climbing threatens energy balance more than walking on the level. While climbing a staircase may seem a trivial bodily movement, it has been estimated that climbing one 6.44 m staircase costs 5.9 kcal (Eves et al., 2009), equivalent to 0.7% of the energy available for all bodily movements on an average day (Levine & Kotz, 2005). Stair navigation begins early in the exploratory ramblings that lead to a bipedal gait; most 11-month-old infants, around 80%, crawl upstairs before they walk upright (Berger et al., 2007). Repeated exploration of staircases from infancy onwards must entail learning about the experience of climbing that is an unavoidable property of staircases. Climbing is energetically costly and 'felt' effort when climbing is a biological proxy for the actual cost. Learning would be cue-dependent through associative processes that have been labelled 'impulsive' in dual-process models (Strack & Deutsch, 2004). We propose that learning about the 'felt' effort associated with climbing makes staircases salient cues about locomotor function in environmental contexts where climbing is avoided.

Contexts can direct search to regions within them. When a target location within a context is repeated, search for that target is progressively facilitated across repetitions (Chun 2000; Chun & Jiang, 1998; Goujon et al., 2015). Much of this research on contextual cueing has used meaningless arrays and was based on implicit learning, dependent primarily on local features that surround the target (Chun, 2000; Olson & Chun, 2002; see also Goujon et al., 2015). Real-world scenes also cue search; fewer repetitions are required than for implicit learning with arrays (Brockmole et al., 2006; Brockmole & Henderson, 2006a, 2006b; Henderson, 2017). The explicit learning is initially based on global features of the scene (Brockmole et al., 2006; Brockmole & Henderson, 2006a; Henderson, 2017). Semantics of the scene are not a prerequisite for learning; the complexity of the scenes provides unique cues that facilitate explicit learning (Goujon et al., 2012). We used cued search in contexts with staircases to test learning related to the content of those contexts.

Contextual cueing was adapted to test for learning biased by content. Pictures of real-world staircases can elicit equivalent percepts to their real-environment counterparts (Taylor-Covill & Eves, 2013) and these percepts can be influenced by potential energetic costs (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2016). In our experiments, participants searched for letter targets in scenes with and without staircases. The staircases were presented face-on, the orientation seen by pedestrians on approach and that associated with resources (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2014, 2016). The potential climb offered by a staircase was an incidental feature of the context; participants were not searching for staircases but rather for letters in different contexts. Proximity of the target to the salient scene feature of a staircase, near as opposed to far, was the major experimental manipulation. Near and far targets were equiprobable. If learning is biased because of staircase salience, better cueing for targets close to a staircase, than for those farther from it, should occur. Scenes of buildings without staircases served as control stimuli and, as such, we predicted response latencies would be intermediate between those facilitated, near trials, and those that might be inhibited, far trials.

The exploratory experiments, reported here, acted as a filler task in a study on the potential effects of resources on perception of pictures of hills and staircases. The overarching design for this study was to recruit a balanced sample of men and women who were randomly allocated to fasting or no-fast conditions. Fasting participants consumed no food from 8:00 pm the previous night whereas the no-fast participants ate meals normally and consumed a flapjack (329 kcal) when they reported to the laboratory. The response latency task served to further deplete the resources of fasted participants (Gailliot et al., 2007) and to allow absorption of the snack bar in the no-fast participants. Clearly, energetic and, therefore, locomotor resources would be depleted in the fasting group.

2.3 Experiment 1

2.3.1 Methods

2.3.1.1 Participants

Eighty students (33 F, 47 M; mean age 20.14 years, *SD* = 1.05) participated in this study after providing informed consent. As there was no prior evidence on which to base a power calculation, we recruited an adequate sample for what we expected to be a small effect size. Upon completion of the testing session, participants were paid £5 compensation. Twelve participants were excluded from analyses due to equipment problems as well as one participant, who gave 50% incorrect answers. For one of the twelve excluded participants, software problems occurred only in the ninth block; for this individual, the data were included in combined analyses over the first eight blocks (section 2.4.3).

2.3.1.2 Stimuli

Stimuli belonged to one of three stimulus categories with the target, a letter, located near to a staircase, far from a staircase, or in a scene with a building (and without a staircase; for example, stimuli see figure 1.1). We aimed to equate the categories for explicit difficulty, tested with a stimulus rating task. The procedure and results of the stimulus rating study are given in the appendix. If search is biased towards staircases, we would expect stronger contextual cueing for targets close to staircases than for targets that were placed at a distance from staircases or in scenes without staircases.

A total of 570 full-colour photographs of real-world outdoor scenes from the West Midlands were taken in and around Birmingham (UK) with a Canon EOS 100D camera, enabling a resolution of 5184 by 3456 pixels. Staircases had to have at least nine steps and take up no more than 20% of the picture. The pictures of buildings did not contain any slants so that they acted as a control condition for scenes of the built environment to compare with staircase scenes. To reduce potential interference with search, people were excluded from all pictures (Foulsham et al., 2011). Additional constraints were that the pictures of staircases were taken so that they were presented always in the direction of travel, equally often on the right- and left-hand sides of the pictures. This positioning was to ensure that the staircases pointed at the participant, the orientation seen by pedestrians upon approach and the one associated with resources (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2014, 2016). We tried to ensure that pictures of all stimulus categories appeared similar in complexity. This consideration is important since fixations have been found to be more abundant in areas with a greater degree of edge density (see Henderson, 2003).

180 pictures were chosen and a letter, L or T (light grey; Arial font size 18), was then added onto each picture, using the image editing programme GIMP (Kimball & Mattis, 2013, version 2.8.10, www.gimp.org). When doing so, three stimulus categories of pictures were created: pictures with a letter close to a staircase (near category), pictures with a letter far from a staircase (far category) and pictures with a letter on or near a building (building category). Six pictures of each category, near, far, and building, were chosen to be repeated stimuli (see figure 1.1 for an example picture of each category). Target locations in repeated scenes of all stimulus categories were equally likely on both sides of the screen, high and low, as well as roughly balanced for apparent difficulty and backgrounds (e.g., greenery vs. built environment). The other stimuli were novel, meaning they were shown only once to participants. For

these, 54 pictures of each category, near, far, and building, were selected. All three stimulus categories were equiprobable.

During repetitions, the target location remained the same, whereas the target identity (T / L) changed. Target identity was randomly determined, with the constraints that each repeated scene needed to contain each letter half of the time and no more than three successive repetitions of one picture used the same letter.

Figure 1.1

Example Stimuli of the Near, Far, and Building Categories

Note. These are example stimuli, with a target letter T, that were repeated near the staircase (left picture, target is to the left at the bottom of the staircase), far from the staircase (middle picture, target is on the right hand side on the black car) and in a building picture without a staircase (right picture, target is to the left of the white car on the kerbstone). Stimuli were presented in colour.

Target locations for the three stimulus categories, near, far, and building, were assigned in triplets. Each triplet included one stimulus of each category with similar apparent complexity and the same distance from the target location to the centre of the scenes. Reaction times from pilot participants were used to estimate the difficulty of the stimuli and to exclude stimuli with particularly short or long response latencies. In equating the distance to the centre of the pictures within triplets, we aimed to control for central fixation biases (Foulsham et al., 2011; Tatler, 2007). A grid with 6 x 8 squares was used (1024 x 768

– width of 128 pixels per square) to position the targets evenly across the screen. The two top rows and the two middle columns were kept empty of targets to satisfy the constraints of near and far from staircase categories. This spacing also required participants to search from the centre to more peripheral locations. The same number of targets in each category was placed on the left and on the right side of the picture, near and far from a staircase. In the control condition with buildings, roughly every third target was placed on the building. The grid was also used to establish criteria for the stimulus categories 'near to staircase' and 'far from staircase', such that 'far' targets were at least 2 - 3 squares removed from the staircase (256 - 384 pixels), whereas 'near' targets were up to a maximum of one square removed from the staircase (128 pixels).

In the final block of experiment 2, target locations were changed. Targets that were previously near a staircase were moved to satisfy criteria of 'far from staircase' targets. Scenes with targets that were previously far from a staircase became 'near staircase' stimuli. The two top rows and the two middle columns, as before, were kept empty of targets. Targets in all scenes were moved at least 3.5 squares (448 pixels) from their previous location. This included a change of sides (left, right) in all cases, and a change of height within the image for most targets.

2.3.1.3 Procedure

Each participant was provided with an information sheet and gave informed consent prior to commencing. Participants were asked to sit in front of a 24-inch flat ASUS monitor, with a resolution of 1920 x 1080, 32-bit colour and a refresh rate of 60 Hz, where they would see a series of pictures on a light grey background. They were required to search for a small grey letter L or T in each picture. They were instructed to do this as quickly and accurately as possible and, upon finding the letter, to press the respective key, L or T, on the keyboard. The keyboard positions of the letters L and T were also indicated on the left and right side below the monitor to make explicit the side for participants. Stimulus timing and presentation were controlled by the E-Prime software (Psychology Software Tools, 2016). The experiment was structured to allow for 18 practice trials before the main experiment. In the first experiment, participants saw either the same 18 stimuli repeated nine times (repeated condition) or 18 novel stimuli in each of the nine blocks, a total of 162 novel stimuli, none repeated (novel condition). In the second experiment, target locations changed in the ninth block, the final block of the repeated condition. Target locations in scenes of the near and far stimulus categories switched category; near became far and vice-versa (for more details see section 2.4.1.2). Both experiments included two compulsory breaks after one and two thirds of the experiment (mean total length was 12 min, *SE* = 0.22 min). Between searching the scenes, participants were asked to look at a blue fixation circle presented on the same light grey background in the centre of the screen and press the space bar to view the next picture. Trials were terminated automatically after 20 seconds if no response was given within that time. Following the session, participants completed a short demographics questionnaire. Prior to recording height (Seca Leicester Height Measure) and weight (Seca 877 scale), participants removed their footwear.

2.3.1.4 Design

A mixed design was used to compare learning of trial type, novel versus repeated scenes, between-subjects, with the three stimulus categories, near, far, and building, a within-subjects factor. Each block contained the same number of easy, medium, and difficult stimuli of each category. In the repeated-pictures condition, participants were presented with nine blocks of 18 repeated scenes whereas in the novel condition, participants viewed 18 novel pictures in each block. The stimulus order was counterbalanced using an 18 x 18 Latin square. Each cell within the Latin square, 1 to 18, was assigned a category, near, far, or building, and the side of the screen where the target would be (left or right). Repeated stimuli were each assigned a cell, resulting in very similar average sums of serial position in the sequence for the three stimulus categories, near (1462.17), far (1462.67), and building (1462.82). Average sums of serial position for target identity were also similar, T (26812) and L (25838). The order of presentation was reversed for half of the participants in each group.

2.3.1.5 Data reductions and statistics

Incorrect trials (1.2%) and no-response trials (1.7%) were deleted prior to analyses. A total of 67 / 80 participants with complete data (26 F, 41 M; mean age 20.13 years, *SD* = 1.06) and 97.0% correct trials were included in the following analyses. Since short reaction times were most frequent, the distribution had a substantial positive skew and kurtosis. We reciprocally transformed values to improve the distribution. To back-transform slope values, a pooled value across conditions was used as there were significant differences between stimulus category means. Bonferroni correction was applied to significance levels when comparing multiple means using *t*-tests unless stated otherwise. Potential violations of sphericity (Mauchly test < .05) were treated by adjusting the degrees of freedom using the Greenhouse-Geisser correction.

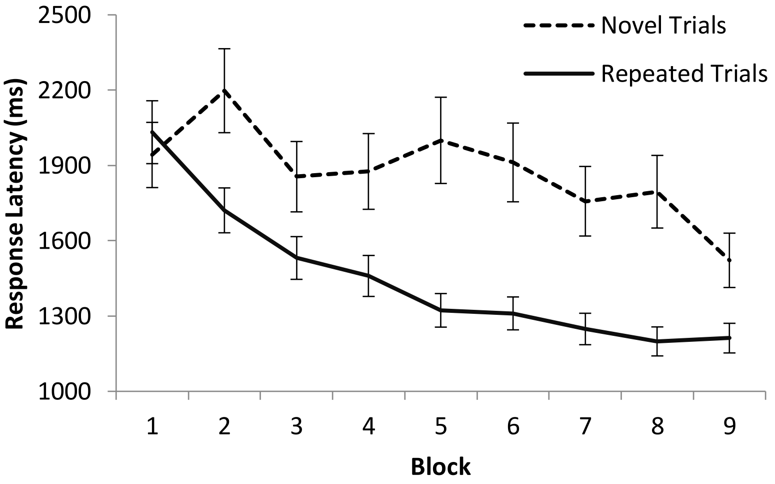
2.3.2 Results

2.3.2.1 Learning in novel and repeated trials

A mixed methods ANOVA was employed to test for differential learning between novel and repeated trials (between-subjects) across the nine blocks (within-subjects; $N = 67$). Figure 1.2 depicts learning in novel and repeated trials across blocks.

Figure 1.2

Learning in Novel and Repeated Trials across Nine Blocks in Experiment 1



There was a main effect of trial type, novel vs. repeated, $F(1, 65) = 54.21$, $p < .001$, $\eta_p^2 = .455$, a main effect of block, $F(6, 386) = 100.71$, $p < .001$ $\eta_p^2 = .608$, and an interaction between the two $F(8, 520) = 35.48$, $p < .001$, $\eta_p^2 = .353$. For the interaction, the linear component explained the majority of the variance, 57%, $p < .001$, (quadratic 30%, $p < .001$). Looking only at novel trials ($N = 30$), there was a significant learning effect over blocks, $F(5, 146) = 20.56$, $p < .001$, accounted for mainly by the linear polynomial (58%, $p < .001$; quadratic 14%, $p < .001$). To further analyse and compare learning between novel and repeated trials, linear regression analyses for each participant across blocks were conducted for each trial type to determine the slope of the linear line that better explained learning. A paired samples *t*-test revealed steeper learning slopes for repeated trials, -96 ms, 95% confidence intervals (CI) [-104.9, -86.4], compared to novel trials, -37 ms, 95% CI [-45.7, -28.5]; *t*(65) = 8.84, $p < .001$, *d* = 2.19.

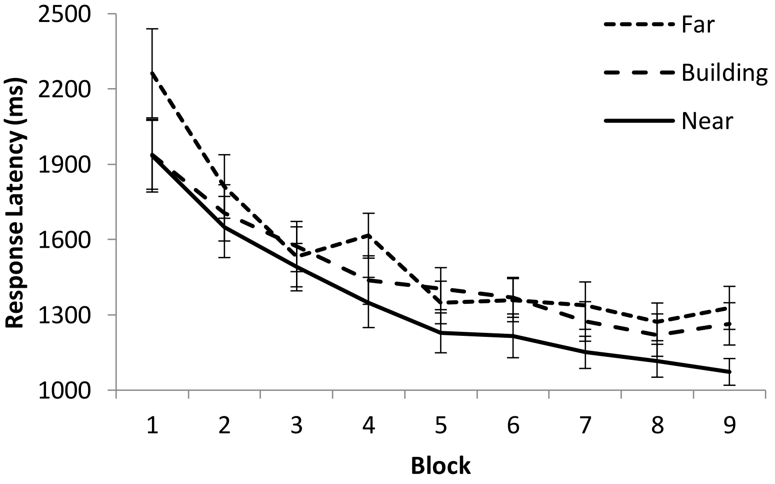
2.3.2.2 Learning in near, far, and building trials

For analyses of potential differential learning between stimulus categories across the nine blocks, only participants of the repeated scenes condition were included (*N* = 37; 14 F, 23 M; mean age 20.22 years, *SD* = 1.00).

A repeated ANOVA with the within-subjects factors of stimulus category (near, far, building) and block (1 - 9) revealed main effects of block, *F*(5, 172) = 134.59, $p < .001$, $\eta_p^2 = .789$, stimulus category, *F*(2, 72) = 41.46, $p < .001$, $\eta_p^2 = .535$, and an interaction between the two, *F*(16, 576) = 5.14, $p < .001$, $\eta_p^2 = .125$. Figure 1.3 depicts the learning in repeated trials for the stimulus categories, near, far, and building, across blocks.

Figure 1.3

Learning in Repeated Near, Far, and Building Trials across Nine Blocks in Experiment 1



Linear trends explained most of the variance across blocks in the near (96%, η_p^2 = .663; quadratic 4%, η_p^2 = .027), far (81%, η_p^2 = .500; quadratic 14%, η_p^2 = .083), and building (93%, η_p^2 = .546; quadratic 5%, η_p^2 = .030) categories. As before, linear regression analyses for each participant across blocks were conducted that confirmed differing learning rates between stimulus categories, *F*(2, 72) = 14.68, $p < .001$, η_p^2 = .290. Follow-up *t*-tests showed that, on average, learning was more rapid across blocks in the near category, -92 ms, 95% CI [-100.8, -83.9], compared to the far, *t*(36) = 4.09, $p < .001$, *d* = 0.67, -70 ms, 95% CI [-79.7, -60.7], and building categories, *t*(36) = 5.80, $p < .001$, *d* = 0.95, -66 ms, 95% CI [-76.8, -56.1].

2.3.3 Discussion

Consistent with previous research on contextual cueing, repeated exposure to real-world scenes with targets in the same locations facilitated learning with large effects sizes. In addition, there was some learning across blocks for the novel trials which might reflect learning of useful ‘algorithmic operations’ (Chun & Jiang, 1998, p. 65) such as knowledge about contrast, e.g., colour of target, and general probabilities, e.g., targets never appear in the sky. For the repeated stimuli, there was differential learning between stimulus categories, such that target locations near staircases were learnt more rapidly compared to those in far and building scenes. This finding supports the hypothesis that the salient scene feature of a staircase can bias search towards its location and facilitate learning of target locations in the near category.

The second experiment tested the strength of learnt associations by changing target locations in the final block, once the participants had learnt the locations during the previous repetitions. We predicted that relocation of targets farther from a staircase would be more difficult, requiring longer search times, compared to relocation nearer to a staircase; response times in control trials were expected to be intermediate. Participants were presented with the same repeated stimuli from experiment 1 for eight blocks, followed by one block with changed target locations. In this new 9th block, targets that were previously near a staircase were relocated farther from that staircase and, concomitantly, targets far from a staircase were relocated close to it. The location of targets in control trials was also changed. We predicted differences in the effects of relocation relative to content of the scene context.

2.4 Experiment 2

2.4.1 Methods

2.4.1.1 Participants

Sixty-four new students (39 F, 25 M; mean age 20.22 years, *SD* = 1.05) were recruited and presented with the same repeated and novel scenes as in experiment 1. Each participant provided informed consent and was paid £5 upon completion of the testing session. The procedure equalled that of experiment 1. Importantly, the 9th block showed the targets in changed locations. Twelve participants were excluded from analysis due to technical difficulties.

2.4.1.2 Stimuli

The same stimuli and stimulus categories as in experiment 1 were used. In addition, in the new 9th block, the repeated condition contained stimuli with targets in changed locations. New target locations were chosen to be balanced across stimulus categories in apparent complexity, in distance from the centre and whether they appeared on the left or right side of the screen. The changed locations were always at least 3.5 squares (448 pixels, image definition overall: 1024 x 768 pixels) from the old locations. Targets that were previously located far from a staircase were now relocated close to a staircase and vice versa.

2.4.1.3 Procedure

Participants underwent the same procedure as in experiment 1 with the difference that targets in the repeated condition changed locations in the 9th block (final block).

2.4.1.4 Design

The design was the same as in experiment 1.

2.4.1.5 Data reductions and statistics

As in experiment 1, incorrect trials (1.7%) and no-response trials (1.3%) were deleted prior to analyses. A total of 52 / 64 participants (32 F, 20 M; mean age 20.16 years, *SD* = 1.02) and 97.1% correct trials were included in the following analyses. Reciprocal transformation of response latencies, back-transforming of slope values, Bonferroni correction of significance levels in multiple comparison *t*-tests, and Greenhouse-Geisser correction were all performed as described in section 2.3.1.5 for experiment 1.

2.4.2 Results

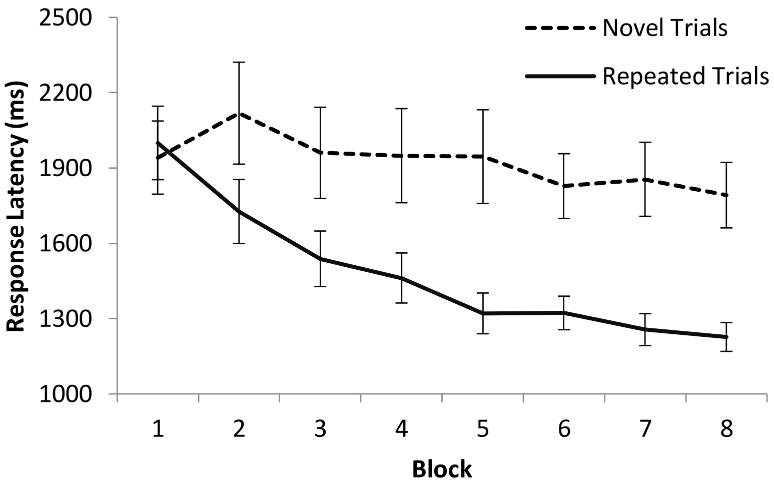
2.4.2.1 Learning in novel and repeated trials

Below, we briefly summarise the effects across the first eight blocks for comparison with experiment 1. Fuller treatment of these effects is reported in a combined analysis of both studies that includes potential effects of resources.

A mixed methods ANOVA replicated differences in learning between novel and repeated trials (between-subjects) over the first eight blocks (within-subjects; *N* = 52) with main effects of trial type (novel vs. repeated), block, and an interaction between the two (all $p < .001$, all $\eta_p^2 > .346$). Learning in novel and repeated trials across the first eight blocks is shown in figure 1.4. Linear regression per participant replicated steeper learning slopes for repeated trials, -109 ms, 95% CI [-121.4, -97.4] than for novel trials, -23 ms, 95% CI [-36.6, -9.1], $t(50) = 9.47$, $p < .001$, $d = 2.68$.

Figure 1.4

Learning in Novel and Repeated Trials across Eight Blocks in Experiment 2

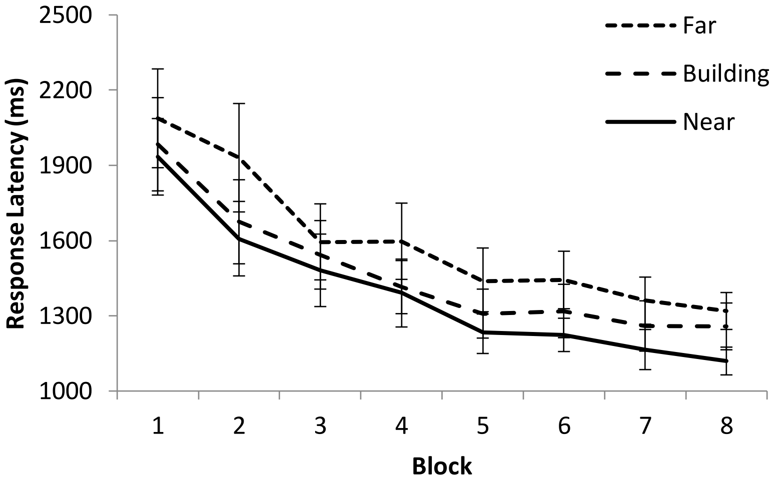


2.4.2.2 Learning in near, far, and building trials

For participants of the repeated scenes condition (N = 27; 16 F, 11 M; mean age 19.82 years, SD = 0.96), a repeated ANOVA across the first eight blocks replicated main effects of block and stimulus category, (both $p < .001$, both $\eta_p^2 > .577$), with a significant interaction between the two, $p = .041$, $\eta_p^2 = .064$, of smaller effect size than in experiment 1, i.e., $\eta_p^2 = .125$. Mean back-transformed response latencies per stimulus category across the first eight blocks are plotted in figure 1.5.

Figure 1.5

Learning in Repeated Near, Far, and Building Trials across Eight Blocks in Experiment 2



Most variance across blocks was explained by the linear polynomial in near (96%, η_p^2 = .641; quadratic 3%, η_p^2 = .021), far (93%, η_p^2 = .500; quadratic 4%, η_p^2 = .020), and building (90%, η_p^2 = .513; quadratic 9%, η_p^2 = .053) categories. Individual regression analyses replicated differing learning rates, *F*(2, 52) = 5.39, *p* = .007, η_p^2 = .172, in that near stimuli produced steeper learning slopes across blocks, -99 ms, 95% CI [-112.3, -86.5], than stimuli of the far, -77 ms, 95% CI [-89.9, -64.0], *t*(26) = 2.81, *p* = .009, *d* = 0.54, and building categories, -79 ms, 95% CI [-91.7, -66.9], *t*(26) = 2.62, *p* = .015, *d* = 0.50.

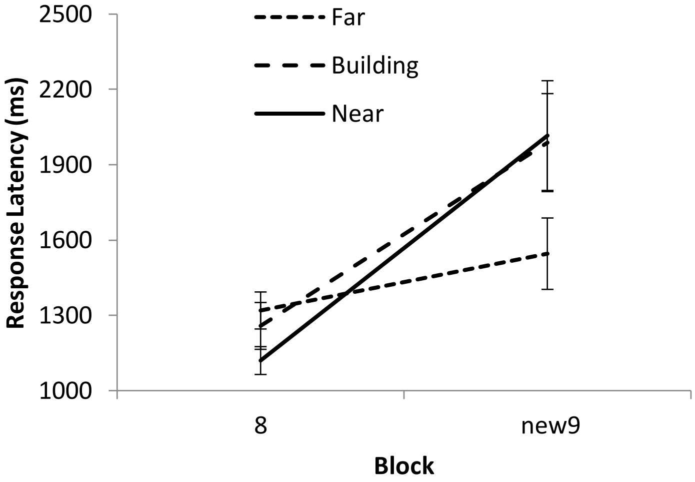
2.4.2.3 Changed locations in near, far, and building trials

A repeated ANOVA was used to test for differential reaction times in the stimulus categories near, far, and building from block 8 to block 9, where target locations changed (*N* = 27; see figure 1.6 for back-transformed mean response latencies). There was a main effect of block (block 8 vs. new block 9), *F*(1, 26) = 167.55, *p* < .001, η_p^2 = .866, stimulus category (near, far, building), *F*(2, 52) = 4.92, *p* = .011, η_p^2 = .159, and an interaction between the two, *F*(2, 52) = 32.53, *p* < .001, η_p^2 = .556.

Follow-up *t*-tests on block 8 revealed differences between near and both far, *t*(26) = 6.07, *p* < .001, *d* = 1.17, and building categories, *t*(26) = 3.73, *p* = .001, *d* = 0.72. This suggests that, by block 8, near stimuli had been learnt to a greater extent than far and building stimuli.

Figure 1.6

Response Latencies in Repeated Near, Far, and Building Trials in Blocks 8 and new9 in Experiment 2



Note. Response latencies are depicted for the previously learnt target locations on block 8 and the changed target locations in block 9 (new9).

To compare block 8 with the changed target locations in block 9, we calculated change scores and compared those using *t*-tests. All stimulus categories differed significantly, with slowing in near trials (*M* = +1037 ms, *SE* = 113 ms) being greater than slowing in buildings trials [*M* = +802 ms, *SE* = 98 ms, *t*(26) = 3.10, *p* = .005, *d* = 0.60] which in turn was greater than slowing in far trials [*M* = +309 ms, *SE* = 93 ms, *t*(26) = 4.67, *p* < .001, *d* = 0.90].

2.4.3 Experiments 1 and 2 Combined Results

To test for omnibus effects of resources on learning in this exploratory study, we combined the data from studies 1 and 2 across the first eight blocks. The first eight blocks were the same between experiments. A mixed ANOVA was conducted with two within-subjects factors of stimulus category (near, far, building) and block (first eight blocks) and three between-subjects factors of trial type (novel, repeated), gender (female, male) and hunger status (sated, fasted), with BMI, mean centred for each sex, as a covariate. The analysis included all participants who had completed the first eight blocks (N = 120) and was roughly balanced for gender (58 F, 62 M) and hunger status (61 sated, 59 fasted). The omnibus analysis confirmed a main effect of trial type, $F(1, 110) = 111.99$, $p < .001$, $\eta_p^2 = .504$ (novel, repeated), a main effect of block, $F(6, 605) = 127.19$, $p < .001$, $\eta_p^2 = .536$, and an interaction between the two, $F(6, 605) = 63.40$, $p < .001$, $\eta_p^2 = .366$. Repeated trials were learnt more rapidly, -112 ms, 95% CI [-120.0, -103.4] than novel trials, -24 ms, 95% CI [-32.1, -15.0], $t(118) = 14.44$, $p < .001$, $d = 2.66$.

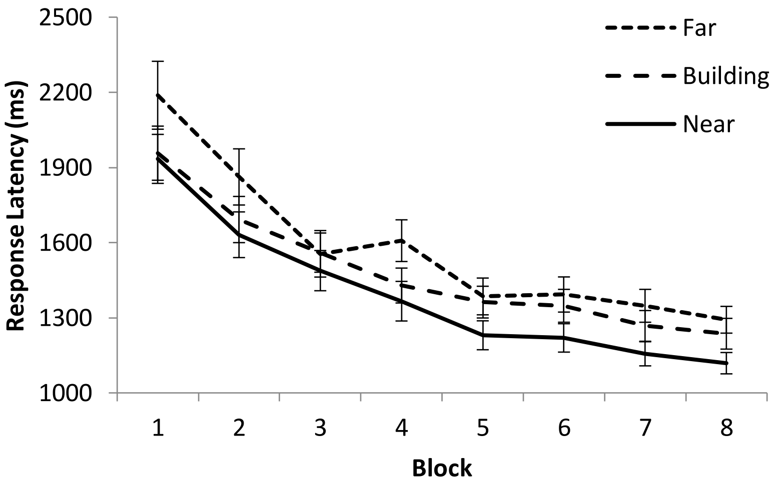
On average, sated participants, M = 1595 ms, SE = 30 ms, found targets quicker than fasted participants, M = 1709 ms, SE = 34 ms, $F(1, 110) = 5.94$, $p = .016$, $\eta_p^2 = .051$. There were no interactions of learning in stimulus categories in novel and repeated trials across blocks with the resource-related variables of sex, $F(11, 1257) = 0.876$, $p = .585$, $\eta_p^2 = .008$, fasting, $F(11, 1257) = 0.810$, $p = .634$, $\eta_p^2 = .007$, or BMI, $F(11, 1257) = 0.715$, $p = .730$, $\eta_p^2 = .006$.

For the following analysis, only participants of the repeated condition are included. These were 64 participants, 30 of whom were female and 34 were male, 34 were sated and 30 were fasted. There was a main effect of block, $F(5, 291) = 206.66$, $p < .001$, $\eta_p^2 = .778$, a main effect of stimulus category, $F(2, 118) = 63.55$, $p < .001$, $\eta_p^2 = .519$, and an interaction between the two, $F(10, 606) = 4.16$, $p < .001$, $\eta_p^2 = .066$. A follow-up ANOVA confirmed significant differences between learning slopes in the three stimulus categories, $F(2, 126) = 11.52$, $p < .001$, $\eta_p^2 = .155$. Learning was mostly linear in all categories: near (96%, $\eta_p^2 = .637$; quadratic 4%, $\eta_p^2 = .023$), far (90%, $\eta_p^2 = .524$; quadratic 6%, $\eta_p^2 = .040$), and building (95%, η_p^2

= .545; quadratic 4%, η_p^2 = .023). Follow-up *t*-tests revealed a steeper learning slope across blocks for targets near staircases, -101 ms, 95% CI [-109.2, -92.2] compared to target locations in the far, -82 ms, 95% CI [-91.0, -73.5], *t*(63) = 3.45, *p* = .001, *d* = 0.43, and building categories, -79 ms, 95% CI [-87.5, -70.3], *t*(63) = 4.55, *p* < .001, *d* = 0.57. Averaging response latencies across the first eight blocks, targets in near trials have been found quickest (*M* = 1350 ms, *SE* = 26 ms), followed by targets in building trials (*M* = 1450 ms, *SE* = 30), which in turn have been found quicker than targets in the far stimulus category [*M* = 1534 ms, *SE* = 31; all pairwise comparisons *t* > 5.131, *p* < .001; *F*(2, 126) = 62.15, *p* < .001, η_p^2 = .497]. Mean back-transformed response latencies are depicted in figure 1.7.

Figure 1.7

Learning in Repeated Near, Far, and Building Trials across Eight Blocks in Experiments 1 and 2



Concerning potential effects of resources on learning, there were no further interactions of the resource variables with the effects of stimulus category over blocks (all *p* > .494). There were no differences between the sexes in slopes across blocks, *F*(10, 606) = 0.942, *p* = .495, η_p^2 = .016, nor between fasted and sated participants, *F*(10, 606) = 0.895, *p* = .540, η_p^2 = .015, nor associations with BMI, *F*(10, 606) = 0.928, *p* = .508, η_p^2 = .015. A mixed ANCOVA, following individual slope analyses, confirms that there are no interactions between learning across blocks in the stimulus categories and sex, *F*(2, 118) = 0.513, *p*

= .600, η_p^2 = .009, fasted status, F(2, 118) = 0.265, p = .768, η_p^2 = .004, or BMI, F(2, 118) = 0.138, p = .871, η_p^2 = .002.

2.4.4 Experiment 2 Discussion

Experiment 2 replicated the contextual cueing effect of experiment 1. Repeated blocks were learnt more rapidly than novel blocks, with, once again, some learning in novel trials.

When target locations changed in the 9th block, response latencies slowed as predicted. Target locations in the near category were most difficult to find in the change block, followed by target locations in the building category. The least affected category was response latencies for targets previously placed far from a staircase that had changed to be near that staircase. The initially far category benefitted from the change relative to control scenes since it now contained targets near to the salient scene feature of a staircase.

Unsurprisingly, across the first eight blocks of experiments 1 and 2 combined, target locations close to a staircase were learnt more rapidly than those farther from it or in control scenes without a staircase. In these analyses of learning, there were no effects associated with locomotor resources. Neither sex nor fasted status influenced the speed of learning across categories. The only resources related significant effect was that, overall, fasted participants were slower than sated ones, possibly reflecting reduced self-regulation at lower levels of glucose (Gailliot et al., 2007). Proffitt (2009) argued that effects of resources were unlikely to be found for stimuli that did not afford meaningful climbing. Clearly, pictures cannot be climbed. While effects of resources have been found for life-size displays of staircases (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2016), the participant’s task in those studies was to assess the staircase itself. The task here was letter search within scenes, some of which contained staircases. One could argue that the absence of effects of resources is unsurprising; the staircases were incidental content of the context within which the targets were located.

2.5 General discussion

In both experiments, learning was primarily linear across blocks and much more pronounced in repeated compared to novel trials. Proximity to staircases, that was incidental to the task, was associated with more rapid learning and stronger target-context associations than the other categories. The change block in experiment 2 was consistent with this proposed bias by the salient scene feature of a staircase.

Before discussing the results, one point should be made explicit. Staircase stimuli were more common than building stimuli, 2:1, and the target was near a staircase in half of these scenes. A helpful reviewer suggested that an explicit strategy of searching near a staircase would produce biased learning for near trials because it increased the likelihood of success. Interviews in a subsequent study discount such a strategy. When participants were asked '*Did you use any specific strategies to find the letters*?', only two said they looked at stairs first, with a further three mentioning stairs amidst other objects, i.e., railings, cars, bushes and houses (n = 78; Rosemeyer et al., in preparation 2020a). Contextual cueing is explicit with real-world scenes but 6.4% mentioning staircases does not suggest a preponderance of explicit search near staircases to accomplish the task here.

2.5.1 Contextual cueing with real-world scenes

In contrast to Brockmole and Henderson (2006b) where learning approached asymptote after four blocks in the regression analysis, learning in both experiments here was primarily linear and continuing across all blocks. In Brockmole and Henderson's study (2006b, figure 1), response latencies decreased by 2760 ms (3890 ms - 1130 ms) over the first eight blocks, whereas learning here was slower, with latencies decreasing by 810 ms (2020 ms - 1211 ms). Differences in the number of repeated stimuli, and their level of difficulty, might explain this discrepancy. Whereas Brockmole and Henderson (2006b) had eight repeated stimuli, we used 18 repeated scenes to formally test learning in three different categories; this necessitated learning of a larger stimulus set. Our repeated stimuli also appear to differ from Brockmole and Henderson's in initial difficulty. The first block latencies here (*N* = 64, *M* = 2021 ms, 95% CI [1931, 2112]) were shorter than those displayed in Brockmole and Henderson (2006b, figure 1; *M* = 3890 ms, 95% CI [3340, 4440]). Greater initial difficulty entails a greater learning potential and enables, through longer search times, a more detailed representation of context and target locations therein (Liu & Jiang, 2005; Melcher, 2006).

Perhaps more importantly for the shape of the learning function, the stimuli belonged to two overlapping architectural categories, namely pictures of buildings without staircases and pictures of staircases that also included buildings. Within Tversky & Hemenway's (1983) categorization, our stimuli belonged to a single environmental category of city. Brockmole and Henderson's repeated stimuli were from three environmental categories: home, park, and city (Brockmole, personal communication June, 2018[1]). The relative uniqueness of each of Brockmole and Henderson's (2006b) stimuli may have facilitated learning (Diamantopoulou et al., 2011; Goujon et al., 2012; Melcher & Murphy, 2011; Mruczek et al., 2019; Yang et al., 2018). Here, primarily linear learning functions, continuing across nine blocks, resemble more the slower learning that occurs for implicit contextual cueing (Chun & Jiang, 2003; Goujon et al., 2015). Learning in real-world scenes can be explicit but repetition will inevitably result in the acquisition of implicit knowledge (Berry & Dienes, 1993; Brockmole & Henderson, 2006b; Chun & Jiang, 2003; Cleermans et al., 1998; Goujon et al., 2015; Jimenez & Mendez, 2001).

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[1] We thank James Brockmole for providing us with the stimuli used in his study.

2.5.2 Biased learning to search near staircases

As predicted, target locations near to the salient scene feature of a staircase were associated with steeper learning curves than target locations remote from staircases or in scenes without them. Moving targets away from staircases resulted in a considerable lengthening of latencies (+1037 ms, 95% CI [+815.5, +1258.5] relative to control scenes without staircases (+802 ms, 95% CI [+609.9, +994.1], with targets moved near to a staircase the least affected (+309 ms, 95% CI [+126.7, +491.3]. These findings compliment biased learning. Greater disruption when a target was moved farther from that staircase may be an epiphenomenon of greater learning accrued in near trials. The least disruption for relocation of targets near to a staircase provides triangulation in this exploration of biased search towards staircases. The content of the context, specifically the salient scene feature of a staircase, can influence cueing of search in real-world scenes.

Environmental objects with which one could interact can be perceived for the actions they 'afford' based on proportions of an individual's physical size, e.g., eye height (Gibson, 1979; Mark, 1987; Mark & Vogele, 1987; Warren, 1984; Warren & Wang, 1987). Proffitt (2006) proposed that the energetic cost of the action also influenced perception. Available resources were said to modulate perception in a way that supported an 'economy of action' that would maximise energy net gain (Proffitt, 2006, p. 111). Consistent with Proffitt's hypothesis, exaggerated perception of the slant of staircases and hills, called geographical slant perception, is linked to an individual's available resources. In experimental studies, fatigue (Bhalla & Proffitt, 1999; Proffitt et al., 1995; Taylor-Covill & Eves, 2013), depleted glucose resources (Schnall et al., 2010) and carrying extra weight in a backpack (Bhalla & Proffitt, 1999), all increased participant's estimates of the slant of a potential climb. While experimental demand has been proposed as an explanation (e.g., Durgin et al., 2009; Durgin et al., 2012), quasi-experimental studies with group allocation based on behavioural choices or physique confirmed effects of glucose resources (Taylor-Covill & Eves, 2014) and additional weight (Eves et al., 2014; Taylor-Covill & Eves, 2016). Experimental demand was an unlikely explanation; participants were interviewed about the environment when waiting for their train. Importantly, estimates of staircase slant were scaled by the deadweight of body fat carried (Taylor-Covill & Eves, 2016). Females, who have a greater percentage of their body weight as fat than males (McArdle et al., 2007), consistently report more exaggerated slants (Eves et al., 2014; Proffitt et al., 1995; Taylor-Covill & Eves, 2013, 2014, 2016).

In the experiments reported here, staircases were always aligned face-on, in a participant's potential direction of travel, to maximise possible effects on cognitive processes related to resource management. Face-on is the slant offered by a staircase for climbing by a pedestrian and the image orientation consistently associated with effects of resources. We propose that the salient scene feature of a staircase biases learning because of the potential increased metabolic costs of its use relative to level walking. Staircases represent 'prepotent' stimuli to cognitive processes that manage locomotor resources.

In the literature on phobic anxiety, pictures of snakes may act as 'prepared stimuli' in that participants are biased to detect these stimuli quicker than neutral ones, such as flowers. Learnt associations for prepared stimuli are easier to acquire and more difficult to change (Cook & Mineka, 1989; Öhman et al., 1975; Öhman et al., 2001; Öhman & Mineka, 2001; Öhman & Soares, 1993, 1994, 1998; Seligman, 1970; Seligman, 1971). Snakes can be described as prepotent stimuli to reflect a bias that exists prior to the initial encounter in the experiment. This prepotency can result from origins that are phylogenetic, i.e., evolutionary, or ontogenetic, i.e., from prior experience during development (DeLoache & LoBue, 2009; Isbell, 2006, 2009; LoBue & Rakison 2013; Öhman & Mineka, 2001; see also Proffitt & Linkenauger, 2013). A prepotency of staircases could develop from ontogenetic processes, i.e., intra-generational learning, as opposed to phylogenetic acquisition of snake phobia over successive generations (Isbell, 2006, 2009; LoBue & Rakison 2013; Öhman & Mineka, 2001, 2003). Experience of staircase properties, i.e., associated effort of climbing, begins before toddlers walk upright (Berger et al., 2007).

Ontogenetic learning about costs must contribute to a prepotency of staircases as incidental content of a scene.

Nonetheless, limited energetic resources (Levine & Kotz, 2005), the high costs associated with climbing (Ainsworth et al., 2000; Teh & Aziz, 2002) and a propensity to minimise these costs (Eves, 2014, 2020) could have had impacts across generations, so phylogenetic associations could also be relevant. In the test of resources in the combined data set, the biased learning of search towards staircases was independent of resources, despite depletion from an overnight fast. This absence of effects might reflect the use of pictures (Proffitt, 2009) and the incidental nature of exposure during a visual search task. Alternatively, biased learning about staircases might reflect a universal human characteristic that is unrelated to current state, fasted status, and prior experience of climbing staircases carrying additional deadweight in the medium term or biological sex as a long-term contributor to constraints on locomotor resources.

2.5.3 Limitations and future directions

The use of real-world photographs invariably risks potential confounding by features of the scene which may vary systematically with the location of targets. In particular, target locations within near and far categories were not counterbalanced across participants. Some of the differences between staircase categories could have reflected the scenes themselves. Any subsequent study should counterbalance near and far targets across the specific scenes. Unlike in Brockmole and colleagues' studies, the contrast between novel and repeated conditions was tested as a between-subjects factor rather than the within-subjects factor in the earlier research. Future within-subjects designs would test the robustness of the cueing by the real-world scene categories, near, far, and building, used here. Future research should also explore the number of stimulus categories as a potential explanation for the primarily linear improvement across blocks found in both experiments.

The studies here used contextual cueing by incidental scene content to index biased learning to search. Subsequent studies using odd one out designs would more directly test an attentional bias towards staircases as salient stimuli from real-world scenes (LoBue et al., 2014; Öhman et al., 2001). Initial saccades biased towards staircases in the scenes used here suggest that bias would be found (Rosemeyer et al., submitted 2020b). Finally, although we used face-on staircases, exaggerated estimates of slant occurred for side-on views of hills (Proffitt et al., 2001; Witt & Proffitt, 2007), though neither study tested effects of resources. A test of the cueing potential of side-on staircases would be informative about the general category of staircase scenes.

2.6 Conclusion

Contextual cueing explored a potential prepotency of staircases as content of real-world scenes. More rapid learning to find targets near staircases than targets elsewhere may result from their salience. In the change block, targets moved away from staircases were disadvantaged relative to control scenes, whereas targets moved closer were at an advantage. Better learning for targets near staircases, that were incidental to search, may reflect the relevance of staircases to cognitive processes that manage energetic resources. Contextual cueing of search was biased by the content of contexts containing staircases.

2.7 Acknowledgements

We thank David McIntyre for his continuous support with programming E-Prime. We thank James Brockmole for providing us with the stimuli from his study. Finally, we also thank the third-year project students, without whom these data could not have been collected.

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2.9 Appendix: Rating of explicit stimulus difficulty

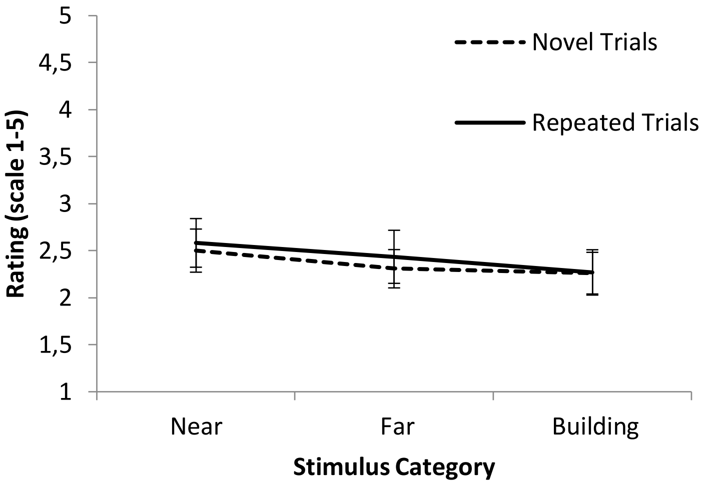
Eighteen participants (10 F, 8 M), who did not take part in the two main experiments, agreed to rate our stimuli for explicit difficulty. No compensation was given. Each participant rated all novel stimuli, 54 near, 54 far, and 54 building stimuli, randomly intermixed with the 18 stimuli that would be repeated, 6 near, 6 far, and 6 building stimuli. For the repeated scenes, either an L or a T was used as the target; half of the participants saw each version. The main stimuli were preceded by six practice trials that were excluded from analyses. Half of the participants rated the pictures in reversed order of presentation.

Each participant was sent an Excel file introducing them to the rating task and providing a table for their answers. The 186 stimuli were numbered, in normal or reversed order, and shared via a Dropbox link. All participants were instructed to 'think how difficult it is to see the letter in the pictures on a scale of 1 (very easy) to 5 (very difficult) in comparison to the letters in the other pictures. We want to know how difficult it is to see the letter NOT how fast you can find it. When you have found the letter, think for a moment how difficult it is to see it and then rate it accordingly.' It was suggested that participants used the whole scale and started searching from the centre of each picture.

A two-way ANOVA compared the explicit difficulty of trial type, novel versus repeated, and stimulus categories, near, far, and building. There was no significant effect of trial type, $F(1, 17) = 1.77$, $p = .201$, $\eta_p^2 = .094$. The stimulus categories, near, far, and building, were rated to differ in explicit difficulty, $F(2, 34) = 9.73$, $p < .001$, $\eta_p^2 = .364$. Trial type and stimulus category did not interact, $F(2, 34) = 0.51$, $p = .608$, $\eta_p^2 = .029$. Follow up *t*-tests revealed suggestive evidence of near stimuli being more difficult ($M = 2.54$, $SE = 0.12$) than far ($M = 2.37$, $SE = 0.12$), $t(17) = 2.54$, $p = .021$, $d = 0.60$, and building stimuli ($M = 2.27$, $SE = 0.11$), $t(17) = 4.49$, $p < .001$, $d = 1.06$, using conventional probabilities. Considering repeated trials alone, stimuli in the near category were, on average, rated to be more difficult than stimuli from the building category, $t(17) = 2.88$, $p = .010$, $d = 0.68$. Mean ratings for novel and repeated trials of each stimulus category are presented below in figure 1.8.

Figure 1.8

Mean Ratings of Explicit Difficulty for Near, Far, and Building Stimuli



Note. Stimuli were used as novel and repeated stimuli in the main experiments, as indicated. In this rating task each stimulus was rated only once.

We have designed our stimuli to be similarly difficult in explicit awareness. The results suggest this has been largely achieved. There was no significant difference in explicit difficulty between stimuli for the different trial types, novel vs. repeated stimuli. Near stimuli were rated as slightly more difficult than building stimuli, though it should be noted that this difference would represent a bias against our main hypotheses.

Chapter three

The two experiments presented in the first experimental chapter provided evidence of cued search influenced by incidental scene content; specifically, learning was most rapid when targets were located close to a staircase. The paper in this chapter aimed to directly test for a potential prepotency of staircase slant. We understand ‘prepotency’ as a property of a salient scene feature that exists prior to commencing the experiment. This chapter further analyses the data presented in chapter two, testing primarily for a bias in initial eye movements and in the total number of fixations needed to find and identify targets on the first presentation of – at least contextually – novel staircase stimuli.

Paper 2

Where the staircase is and how many steps it has;
biased search towards staircases when novel

Rosemeyer, M., Jenkinson, N., & Eves, F. F. (2020). *[Manuscript submitted for publication]*

3 *Where the staircase is and how many steps it has;*
biased search towards staircases when novel

3.1 Abstract

Introduction. Lifelong experience of the effort of stair climbing may have made the perception of staircase slant an important cue for cognitive processes that manage locomotor resources. Staircases can be part of the spatial layout of a scene that can be extracted in one glimpse. Given the importance of staircase slants, their presence may bias visual search as early as the first saccade.

Objectives. This paper explores the potential biasing of search towards staircases, particularly in the first block of novel staircase stimuli.

Methods. Eye movements and response latencies were recorded while participants (*N* = 118) searched real-world scenes for target stimuli that were positioned near to a staircase, far from a staircase, or in a scene without a staircase. For half of the participants, positioning of the targets remained the same across eight blocks, enabling contextual cueing of search by repeated scenes.

Results. Upon the first presentation of novel stimuli, 38.6% of initial saccades were biased towards a 45° arc around the staircase centre, more so the more steps a staircase contained. Staircases with more steps (>13 vs. <14) facilitated target detection near staircases whilst increasing search time and fixations for targets positioned at a distance from staircases. Target locations near staircases were learnt more rapidly than those in control stimuli.

Conclusions. Search was biased towards staircase slants in novel natural scenes on the first saccade. This effect was amplified when the staircase contained more steps. The relevance of staircases as cues to the management of energetic resources is discussed.

3.2 Introduction

Pavlov described a prompt turning of a dog's sense organs in the direction of a new stimulus in his laboratory which he labelled the 'What is it reflex'. Primarily auditory stimuli elicited a realigning of the pinnae, eyes, head, and sometimes the whole body of the dog (Pavlov, 1927; Sokolov, 1963). From the 50s to the 80s, extensive research with physiological reactions investigated orienting with novel stimuli (Bernstein, 1969; Donchin, 1981; Graham, 1979; Graham & Clifton, 1966; Öhman, 1979; Siddle, 1991; Sokolov, 1963). Orienting has been found to re-organise resources to support perception, physically active exploratory behaviour and learning about the new stimulus. Novelty alone did not elicit orienting reliably (Bernstein, 1969; Bernstein & Taylor, 1979). The prerequisite may be better described as stimulus salience, based on bottom-up factors such as intensity and top-down ones such as relevance to an individual or the ongoing task (Downar et al., 2002; Germana, 1969).

Saccadic eye movement to a novel stimulus represents a human equivalent of the orienting response of Pavlov's dog. Anomalous content, that violated the semantics of the scene, did not elicit the initial saccade towards it that indexes orienting (Acunzo & Henderson, 2011; Becker et al., 2007; Harris et al., 2008; Rayner et al., 2009; Võ & Henderson, 2009). For emotionally valenced novel scenes, however, initial saccades were biased towards them (Calvo & Lang, 2004; Calvo et al., 2008; Fernández-Martin et al., 2017; Nummenmaa et al., 2006, 2009). Scene content that is experienced as emotional is a salient feature of a scene that elicits orienting.

Potentially threating stimuli, e.g., snakes, also elicited earlier fixation (Lobue et al., 2014; Rosa et al., 2011; Yorzinski et al., 2014) and they are associated with facilitated search indexed by manual reaction times (Blanchette, 2006; Fox et al., 2007; LoBue & DeLoache, 2008; LoBue et al., 2014; Öhman et al., 2001; Yorzinski et al., 2014). Search for threatening stimuli can occur in parallel in oddball designs, i.e., they are salient stimuli (Blanchette, 2006; Fox et al., 2007; LoBue et al., 2014; Öhman et al., 2001; Öhman et al., 2012). Although Quinlan (2013) has questioned the evidence for privileged processing, responses to masked snakes, e.g., Öhman and Soares (1993, 1994, 1998), coupled with enhanced learning about these phylogenetically relevant stimuli, e.g., Cook and Mineka (1989) and Öhman and colleagues (1975, 1976), is consistent with the importance of potentially threatening stimuli in our evolutionary past (Isbell, 2006, 2009; LoBue, & Rakison, 2013; Öhman & Mineka, 2001, 2003; Öhman et al., 2012). Searches for contemporary threatening stimuli, i.e., guns, knives, syringes, were also facilitated (Blanchette, 2006; Brosch & Sharma, 2005; De Oca & Black, 2013; Fox et al., 2007) and enhanced learning of physiological reactions to guns has been reported (Flykt et al., 2007; Hugdahl & Johnsen, 1989). Ontogenetic learning about these salient stimuli must occur during development (LoBue, 2010; see also DeLoache & LoBue, 2009). Guns imply threat, often, one suspects, with little direct experience; all bar De Oca and Black used participants likely to be inexperienced with guns.

One major threat for humans is energy balance; intake must at least match expenditure. Only about a third of all intake is available for every bodily movement on each day (Levine & Kotz, 2005). Step widths and step lengths, as well as step frequency, are automatically adopted to minimise the metabolic cost of walking in adulthood (Alexander, 2002; Croft et al., 2017; Srinivasan, 2009). Toddlers learning to walk upright fall 17 times and accumulate 2,368 steps each hour as they explore their environment (Adolph et al., 2012). Progressive increases in step length and decreases in step width signal development; with practice, children begin to approximate the regularity of the adult gait pattern that minimises cost (Adolph & Hoch, 2019; Vereijken et al., 2009). Unlike guns, walking involves extensive direct experience as part of development. Using contextual cueing with real-world scenes, we previously reported preferential learning of search for target locations near staircases (Rosemeyer et al., submitted 2020a, 2020b). We proposed that associative learning about the environmental slant that is a staircase, and the effort required to climb it was another example of ontogenetic learning about threat. In this case, the threat was to energy balance.

Staircases are encountered on a daily basis and climbing them is one of the most costly bodily movements of daily life (Ainsworth et al., 2000; Teh & Aziz, 2002). Proffitt (2006) reasoned that the slant of potential climbs represents an environmental cue that can support the management of energetic resources. Most pedestrians avoid climbing stairs when there is an alternative method of ascent (Eves, 2014, 2020; combined *N* = 1,117,647). This avoidance is driven by an exaggerated perception of staircase slant that precedes climbing (Eves et al., 2014; Taylor-Covill, 2013, chapter 7). Energetic costs of locomotion are minimised to preserve limited resources (Levine & Kotz, 2005; Srinivasan, 2009) and staircases threaten this minimisation if chosen. Lifelong experiences of climbing staircases provide an ontogenetic basis for learning about them. Experienced effort of climbing would be linked to the preceding perception of that staircase in an associative manner (Strack & Deutsch, 2004). We proposed that this cue-dependent learning about staircase properties results in a *prepotency* that biases search (Rosemeyer et al., submitted 2020a). We used the term *prepotency* to indicate a bias that exists prior to encountering a new staircase. The salient stimulus of a staircase, particularly on the first encounter, is relevant to cognitive processes that manage energetic resources.

As outlined elsewhere, we adapted contextual cueing to test for learning biased by the content of real-world contexts (Rosemeyer et al., submitted 2020a). This was threatening rather than anomalous content. Staircases were an incidental feature of the scene and participants were not searching for them. Participants searched scenes for letter targets near a staircase, far from a staircase, and in control scenes without a staircase. More effective cueing in repeated scenes occurred for targets near staircases compared to control scenes. Since we reason that biased learning of locations near a staircase reflects a *prepotency* of staircases accrued from prior experience, this bias should be present for novel stimuli containing the salient scene feature of a staircase. Global semantics of a novel scene are available in the gist (Hayes & Henderson, 2019).

Scene gist can be captured in a single glimpse, including spatial layout and some object level information (Castelhano & Henderson, 2008; Fei-Fei et al., 2007; Oliva, 2005). Gist influences the initial saccade that is linked to orienting (Hayes & Henderson, 2019), specifically for emotional scenes (Calvo et al., 2008; Fernández-Martin et al., 2017; Nummenmaa et al., 2009). Here, we report eye movements and response latencies from primarily the first block of trials. This analysis of novel staircase scenes doubles the sample by adding the control group (*N* = 54) to the cueing group (*N* = 64; *cf.* Rosemeyer et al., submitted 2020a).[2] We predicted that initial eye movements towards a staircase would be more likely than in other directions, if orienting is relevant (Fernández-Martin et al., 2017). Moreover, if the importance of staircases as environmental cues hinges on the energetic costs entailed in climbing, we reasoned that the number of staircase steps might serve as a proxy for the potential cost of a given staircase in the scene. Staircases with more steps should be fixated sooner and their associated targets identified more rapidly.

3.3 Methods

3.3.1 Participants

A hundred and forty-four students (72 F, 72 M; mean age 20.17 years, *SD* = 1.05) participated after providing written consent. As there was no prior evidence on which to base a power calculation, we recruited an adequate sample for what we expected to be a small effect size. Participants were compensated for their contribution with £5.

3.3.2 Stimuli

A hundred and eighty real-world photographs were edited using GIMP (Kimball et al., 2013, version 2.8.10, www.gimp.org) to include a light grey target letter L or T. Three stimulus categories were

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[2] Information on contextual cueing of eye movements is presented as supplemental material.

created: one with the letter near to a staircase (near), one with the letter far from a staircase (far) and one with the letter in a scene with a building instead of a staircase (building; for examples see figure 2.1 below). Target locations were balanced across stimulus categories in centeredness, sidedness (left, right) and height. Scenes in all categories were comparable in complexity, $p > .37$ (Donderi, 2006).

Figure 2.1

Example Stimuli with a Target Letter T Near Stairs (left), Far from Stairs (middle) and Without Stairs

Note. Target locations: Near staircase (left picture, target is to the left at the bottom of the staircase), far from staircase (middle picture, target is on the black car and next to the fence), and in a scene without a staircase, building category (right picture, target is left of the white car on the kerbstone).

Low-level image features, such as colour, intensity, and orientation, can bias attention, even of the initial saccade (Itty & Koch, 2000). To test whether the stimuli were biased in low-level features, the Matlab implementation of the saliency toolbox was used to predict successive saccades and fixations based on low-level image features (Walther & Koch, 2006). For the staircase stimuli presented in the first block, angles from the centre of the images to the staircase were compared with angles from the centre of the images to the *first* predicted fixation location. Difference scores with a maximum of 180° were calculated. The distribution, with a mean of 82.0° ($SE = 8.93$) did not differ from a uniform distribution with a mean of 90.0°, $t(35) = 0.90$, $p = .375$, $d = 0.15$. As a second step, we summed the number of predicted fixations until the staircase was fixated. Fixation of the staircase was operationalised as a predicted pixel, within an area of 65 x 65 pixels, that included or touched the stairs within the image. This pixel space is the area expected to be processed by foveal cells (cf. Henderson & Hollingworth, 1999). If the staircase was not fixated within the first 10 saccades, a score of 10 was given. There were no differences in the number of fixations to reach the staircase between near (*M* = 7.50, *SE* = 0.76) and far (*M* = 7.22, *SE* = 0.85) categories, *t*(34) = 0.24, *p* = .810, *d* = 0.08, or between staircases with more (*M* = 6.80, *SE* = 0.92) and fewer steps (*M* = 7.76, *SE* = 0.72; *t*(34) = 0.84, *p* = .409, *d* = 0.29). Finally, we compared the overall saliency of each stimulus presented in the first block of the near, far, and building categories using the final saliency map produced by the toolbox. On average, near (*M* = 5.00, *SD* = 0.29), far (*M* = 5.06, *SD* = 0.29), and building categories (*M* = 4.31, *SD* = 0.29) did not differ in mean saliency, *F*(2, 51) = 2.13, *p* = .130, η_p^2 = .077.

For more information on stimulus preparation, including a rating on explicit difficulty of the used stimuli, please see Rosemeyer and colleagues (submitted 2020a).

3.3.3 Procedure

Having read the participant information sheet, participants gave written consent. The basic paradigm had participants search for small (Arial font size 18) grey target letters, L or T, presented on a 24-inch flat ASUS monitor with a resolution of 1920 x 1080, 32-bit colour and a refresh rate of 60 Hz, in the context of real-world scenes with and without staircases. The scenes were embedded in a light grey background and stimulus timing and presentation were controlled using E-Prime software (Psychology Software Tools, 2016). Participants indicated a found letter by pressing the corresponding key, L or T, on the keyboard in front of them. Notes on each side of the screen served to remind participants of the key's locations on the keyboard. The task was to respond as quickly and accurately as possible. Participants' eye movements were recorded using the SR-Research EyeLink 1000 tower mount system. A chin-and forehead rest ensured a consistent and still head position 70 cm from the screen. Eye position was calibrated with nine fixation samples to map eye data to gaze positions on the screen. Between each stimulus, participants were required to fixate a blue target circle in the centre of the screen, whilst simultaneously pressing the spacebar in order to proceed to the next stimulus. This procedure checked for possible eye-movement drift and ensured that participants began searching for each target from the centre of the screen. Each stimulus was presented for 20 seconds or until a key-press response was made. Participants were provided with 18 practice stimuli before the main experiment. Two breaks, one after each third of the total presentations, structured the main experiment.

Following the target search, participants completed a short demographics questionnaire. Measures of height (Seca Leicester Height scale) and weight (Seca 877 scale) were collected, with footwear removed prior to weighing as is the standard procedure.

Data were collected as part of a project testing for effects of resources on the perception of pictures of hills and staircases. In the previous report of the full data set (Rosemeyer et al., submitted 2020a), there were no meaningful effects of energetic resources and the issue is not addressed further.

3.3.4 Design

Mixed design analyses were reported with the between-subjects factor of trial type (novel scenes, repeated scenes) and the within-subjects factors of stimulus category (near, far, building) and steps (>13 steps, <14 steps). Participants in the novel condition were presented with 9 blocks of 18 novel scenes, whilst 18 scenes were repeated each block in the repeated condition. Stimulus location stayed the same for each stimulus in the repeated condition, however, target identity changed between T and L. Both letters were equiprobable. Each block contained six images of each stimulus category. The stimulus order was counterbalanced with an 18 x 18 Latin Square (see Rosemeyer et al., submitted 2020a) and reversed for half of the participants.

3.3.5 Data reductions and statistics

Prior to analyses, incorrect trials (1.3%) and no-response trials (1.4%) were deleted. Also, twenty-five participants were excluded from analyses, due to software problems, as well as one participant, who gave 50% wrong responses. A total of 118 participants (57 F, 61 M; mean age 20.14 years, *SD* = 1.04) were included in the subsequent data analyses.

The first meaningful saccade was defined as having a duration of at least 30 milliseconds. Typical saccade durations have been reported in the range of 40 to 50 ms in scene perception (Rayner, 2009).

For number of fixations, the initial 200 milliseconds were excluded to minimise potential effects of the preceding obligatory fixations of the display centre (cf. Antes, 1974 first fixation defined as following the first saccade). Short fixations with durations of less than 100 ms were merged. The number of fixations was natural log transformed to reduce skew and kurtosis. Response latencies were reciprocally transformed.

Where multiple means were compared using *t*-test procedures, Bonferroni correction was applied to significance levels. For any potential violation of sphericity (Mauchly test < .05), the degrees of freedom were adjusted, using the Greenhouse-Geisser correction.

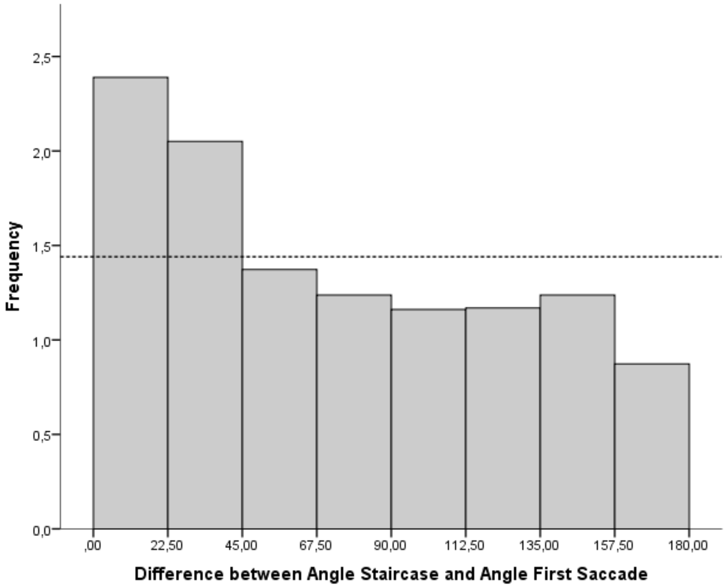
3.4 Results

3.4.1 Direction of the first saccade in staircase scenes

To compare the direction of each first saccade relative to the location of the staircase in each scene in the first block of stimuli, we calculated a difference score in degrees (0° – 180°) that displayed the distance between the mean angle of first saccades for staircase scenes and the angle towards the centre of the staircase in each scene. Figure 2.2 shows a histogram with the frequencies of this difference divided into eight bins of 22.5° (*N* = 118). The furthest possible that the direction of the first saccade could be from the direction of the staircase was 180°, i.e., the complete opposite direction. Out of a total of 12 staircase scenes in the first block, on average 11.492 were correctly found when aggregated across the 118 participants. If direction of first saccades and staircases were unrelated, all distances between the two angles should be equally likely, resulting in a uniform distribution with an average of 1.44 occurrences in each of the eight bins for each participant (see dotted line in figure 2.2). As is apparent in figure 2.2, both the bin from 0° to 22.5° and the one from 22.5° to 45° from the centre of the staircase contained more than the average number of cases. For the first saccade, 38.6% of saccades were directed within 0° and 45° of the centre of the staircases within the scenes. A Kolmogorov-Smirnov test confirmed the absence of an uniform distribution across the bins, $D(118) = 0.15$, $p = .01$. In addition, an omnibus *t*-test (*N* = 118) revealed that the average direction of first saccades (M = 74.44°, SD = 16.90°) differed from a mean of 90° that would indicate no bias, $t(117) = 10.00$, $p < .001$, $d = 0.92$.

Figure 2.2

Distribution of Directions of Initial Saccades relative to Staircase Locations



Note. Frequencies of differences between the angle of the first saccade and the angle towards the centre of the staircase in the scene. The smaller the difference, the closer they were. The dotted line represents a potential uniform distribution across bins.

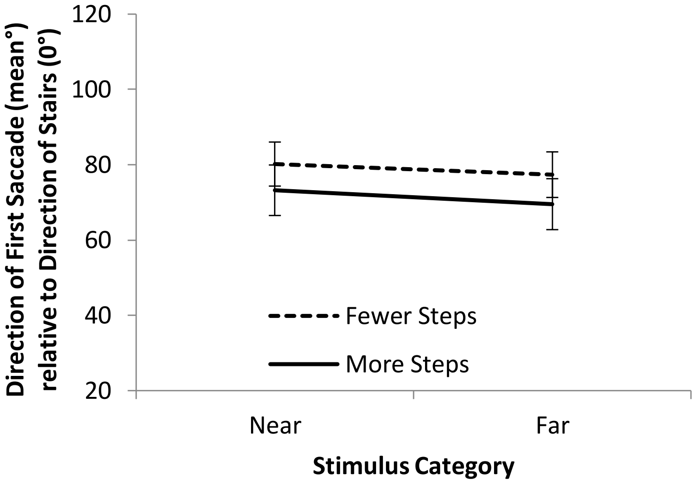
3.4.1.1 Effect of number of steps on direction of the first saccade

The number of steps in a staircase provides information about the potential cost of climbing. The staircase pictures in the first block varied from nine to 41 steps. Although not a design feature of the study, a median split between 13 and 14 steps was used to create a categorical variable of fewer steps (M = 10.9 steps, SE = 0.3 steps) and more steps (M = 19.0 steps, SE = 1.8 steps) for inclusion in the analyses.

A 2x2 ANOVA with stimulus category (near, far) and steps (fewer, more) revealed no interaction between stimulus category and number of steps on the direction of the first saccade ($F < 1$, $p = .889$). There was a significant main effect of steps, $F(1, 117) = 5.34$, $p = .023$, $\eta_p^2 = .044$, such that initial saccades were more likely directed at staircases with a greater number of steps (M = 71°, SE = 2.65°) than at exemplars with fewer steps (M = 79°, SE = 2.29°), irrespective of the location of the target (see figure 2.3 below).

Figure 2.3

Directions of Initial Saccades relative to Direction of Staircase in Near and Far Stimuli with Fewer and More steps



3.4.2 Latency and duration of the first saccade

The average latency of the first meaningful saccade (repeated and novel trials, *N* = 118) for the three stimulus categories, near, far, and building, are displayed in table 1. Since transformations did not improve the normality of the latency distribution, the raw data were used. A repeated ANOVA showed no differences between mean latencies of initial eye movements, in the first block, for the three stimulus categories, $F(2, 215) = 0.05$, $p = .936$, $\eta_p^2 < .001$. The duration of the first saccade was reciprocally transformed to improve skew and kurtosis. A repeated ANOVA revealed that the durations of initial eye movements, in the first block of stimuli, did not differ between stimulus categories, $F(2, 234) = 2.05$, $p = .132$, $\eta_p^2 = .017$ (see Table 1).

Table 1

Latencies and Durations of First Saccades in the Stimulus Categories, Near, Far and Building

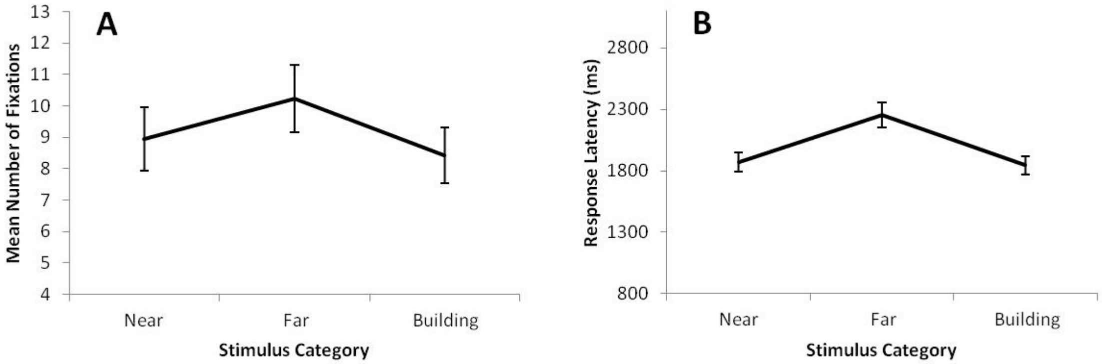
	Mean	SE
Latencies of first saccade		
Near	503 ms	13.49 ms
Far	505 ms	13.22 ms
Building	507 ms	16.38 ms
Durations of first saccade		
Near	48 ms	1.20 ms
Far	46 ms	1.08 ms
Building	48 ms	1.29 ms

3.4.3 First block number of fixations and response latency

Figure 2.4 depicts the average number of fixations and the mean response latency for first block stimuli. As can be seen, a very similar pattern was present across the stimulus categories for the two variables.

Figure 2.4

Mean Number of Fixations (A) and Response Latency (B) in Block 1 for Stimulus Categories Near, Far, and Building



Initially, mixed ANOVAs (*N* = 118) with the between-subjects factor trial type and the within-subjects factor stimulus category compared number of fixations and response latency at the first presentation of stimuli. Both analyses contained main effects of category (Fixations: *F*(2, 232) = 20.99, *p* < .001, η_p^2 = .153; Response latency: *F*(2, 232) = 44.44, *p* < .001, η_p^2 = .277). When response latency was analysed with number of fixations as covariates, there were large magnitude effects of the covariates (all η_p^2 > .489, all *p* < .001). Since main effects in ANCOVA cannot be interpreted with repeated measures designs (Schneider et al., 2015), we computed difference scores between far and the other two categories. Differences in number of fixations accounted for most of the variance in response latency (near vs. far, *adj* R^2 = 0.775; building vs. far, *adj* R^2 = 0.747) and we confine our reporting to effects on eye movements.

For number of fixations, there were no overall differences between trial types, *F*(1, 116) = 0.19, *p* = .667, η_p^2 = .002, but a main effect of stimulus category as described above. Targets near a staircase (*M* = 8.96 fixations, *SE* = 0.51 fixations), *t*(117) = 3.91, *p* < .001, *d* = 0.36, and targets in building pictures (*M* = 8.44 fixations, *SE* = 0.45 fixations), *t*(117) = 6.01, *p* < .001, *d* = 0.55, required fewer fixations than targets that were positioned at a distance from a staircase (*M* = 10.16 fixations, *SE* = 0.56 fixations). There were no differences between the near and building categories, *t*(117) = 1.89, *p* = .061 , *d* = 0.17.

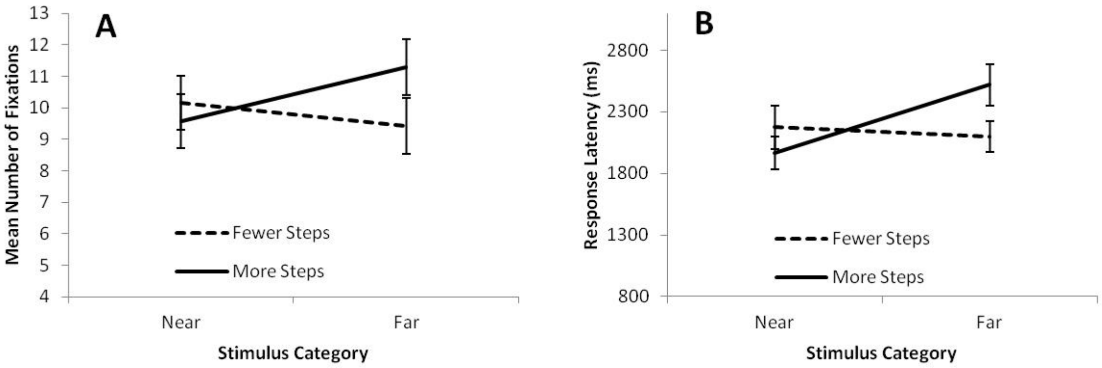
In addition, there was an interaction of stimulus category with trial type, *F*(2, 232) = 7.59, *p* = .001, η_p^2 = .061. Only in the far stimulus category, novel targets required more fixations (*M* = 11.06 fixations, *SE* = 0.95 fixations) than repeated targets [*M* = 9.46 fixations, *SE* = 0.64 fixations; *t*(116) = 2.90, *p* = .004, *d* = 0.54], with Bonferroni corrected significance levels.

3.4.3.1 Effect of number of steps on first block number of fixations and response latency

Figure 2.5 depicts the number of fixations and response latency for near and far staircase stimuli with fewer and more steps. As with the overall effects of category, a similar pattern was present for the two variables.

Figure 2.5

Mean Number of Fixations (A) and Response Latencies (B) in Near and Far Trials for Stimuli with Fewer and More Steps



In repeated ANOVAs (*N* = 118) with the two within-subject factors of stimulus category (near, far) and number of staircase steps (fewer, more), there were interactions between the number of steps and stimulus category, (Fixations; $F(1, 117) = 9.92$, $p = .002$, $\eta_p^2 = .078$: Response latency; $F(1, 117) = 17.19$, $p < .001$, $\eta_p^2 = .128$). When response latency was analysed with number of fixations as covariates, there were significant effects of the covariates on the interaction (all $\eta_p^2 > .489$, all $p < .001$). Differences in number of fixations accounted for most of the variance in response latency for steps (near, $adj\ R^2 = 0.838$; far, $adj\ R^2 = 0.670$) and we confine our reporting to effects on eye movements.

Follow-up analyses of the interaction with difference scores by stimulus category revealed that fewer fixations ($M = -0.88$, $SE = 1.03$) were necessary for targets near staircases with more steps than near those with fewer steps, whereas this relationship was reversed for targets far from staircases, $t(117)$ =

3.15, *p* = .002, *d* = 0.29. For the latter, it was harder (*M* = +2.45, *SE* = 1.03) to find targets when staircases had more steps compared to when they had fewer steps.

3.4.4 Leftward bias

An additional finding was a leftward bias in first saccades for staircase trials in the first block (*N* = 118). An average of 55.5% of first saccades was directed leftwards, 44.5% to the right. This bias was influenced by staircase location. A staircase on the right side of a scene introduced an equally strong search bias to the right, so that first saccades were equally often directed to the left, 24.93%, as they were directed to the right side of the screen, 23.45%. When the staircase was located on the left side, however, initial leftwards saccades were 1.46 times more likely (30.61%) than saccades to the right side (21.02%). This difference was significant, $X^2(1) = 8.26$, $p = .004$. The leftward bias was apparent and similarly pronounced for all stimulus categories, near 57%, far 54%, and building 55% in the first block. An X^2 test confirmed that first saccades in all stimulus categories were similarly biased towards the left side, $X^2(2) = 1.34$, $p = .513$.

3.5 Discussion

3.5.1 Results Summary

On the first presentation of novel scenes containing a staircase, the direction of the initial saccade was biased towards the stairs, more so when staircases had more steps. Fewer fixations were needed to find targets near staircases, relative to targets more distant from staircases. A greater number of staircase steps facilitated target search near staircases, whereas it impeded the search for targets remote from staircases. Response latency to identify targets mirrored the number of fixations. It seems likely that it would be difficult to discriminate the identity of the small targets we used until they had been fixated.

Before discussing the results, one point should be made explicit. Staircase stimuli were more common than buildings, 2:1. One helpful reviewer suggested that an explicit strategy to search near staircases could explain the results. Such a strategy was rare. When asked, '*Did you use any specific strategies to find the letters*?', only two participants out of 78 in a subsequent study reported searching stairs first; three others mentioned stairs amongst other scene elements, i.e., railings, cars, bushes, houses (Rosemeyer et al., in preparation 2020b). Five participants mentioning staircases does not suggest explicit search near them. Effects of scene gist on the initial saccade are involuntary and, hence, an explicit component to the first eye movement seems unlikely (Calvo et al., 2008; Fernández-Martin et al., 2017; Hayes & Henderson, 2019; Nummenmaa et al., 2009). In the first block, target locations were equiprobable between categories and task completion equally rewarded. It seems unlikely that a bias to search near a staircase would develop associatively when a target location far from it was just as probable.

3.5.2 The direction of the first saccade is consistent with a prepotency of staircases

Search was biased on the first encounter with novel staircases; 38.6% of the initial saccades were directed within a 45° arc of the centre of the staircase in the scenes. This bias was greater for staircases with more steps, irrespective of the target location; targets near to and far from staircases were equally affected. This bias was about the location of staircases and their potential climb; it was not about the location of letter targets. There were no effects on the latency or duration of the initial saccade. It should be noted that participants were not searching for staircases unlike biased saccades when identifying emotionally valenced novel scenes in paired or oddball designs (Calvo & Lang, 2004; Calvo et al., 2008; Nummenmaa et al., 2006, 2009; Simola et al., 2013).

Scene gist can be captured within 42 ms of the onset of a scene, with greater activation of the semantics from increased exposure (Castelhano & Henderson, 2008). Gist of a novel stimulus influences the first saccade involuntarily and can use information from extra-foveal locations (Calvo et al., 2008; Fernández-Martin et al., 2017; Hayes & Henderson, 2019; Nummenmaa et al., 2009). Scene gist includes the spatial layout, e.g., a staircase in an urban environment (Oliva, 2005), and may contain functions that can be performed within the scene (Castelhano & Henderson, 2008). Here, the bias by the gist of a novel staircase scene on the initial saccade was somewhat greater for a gist that would require more climbing, consistent with a definition that includes function in scene meaning (Castelhano & Henderson, 2008). The novelty here was for members of a familiar category of environmental stimuli negotiated in the past.

We proposed that a prepotency of staircases that biases search towards their location was learnt from prior experience (Rosemeyer et al., submitted 2020a). The gist of a staircase scene when novel can elicit orienting of the eyes towards the staircase (c.f., Fernández-Martin et al., 2017; Nummenmaa et al., 2009). We suspect this bias may be similar to attentional biases in paired or oddball designs for salient stimuli that signal threat (Blanchette, 2006; Fox et al., 2007; LoBue & DeLoache, 2008; LoBue et al., 2014; LoBue & Rakison, 2013; Öhman et al., 2001) and emotional valence more generally (Calvo & Lang, 2004; Calvo et al., 2008; Fernández-Martin et al., 2017; Nummenmaa et al., 2006, 2009; Simola et al., 2013). The potential threat with staircase scenes was to locomotor resources. Climbing staircases is energetically costly, an order magnitude more than sitting in a workplace (Ainsworth et al., 2000; Teh & Aziz, 2002) and 8.6 - 8.7 times more costly than sitting in laboratory research (Bassett et al., 1997; Eves & White, unpublished). Staircase climbs threaten limited energetic resources (Levine & Kotz, 2005). Staircases represent salient stimuli for cognitive processes that manage resources.

3.5.3 Bias by staircases was moderated by the number of steps.

Targets near staircases were found an average of 1.2 fixations earlier compared to targets located far from staircases. The disadvantage for targets far from staircases was magnified for staircases with more steps whereas the converse was true for staircases with fewer steps. Staircases in scenes impeded search for targets remote from their location, more so the more steps, and hence height of climb they would entail. The prepotency of staircase slants was linked to the potential energetic costs of climbing and, as such, could facilitate the management of energetic resources (Proffitt, 2006; Rosemeyer et al, submitted 2020a).

Near staircase and building categories did not differ in the number of fixations or search latency on the first presentation. Nonetheless, biased learning towards staircases predicted from steeper learning slopes for response latency (Rosemeyer et al., submitted 2020a, 2020b) were confirmed for fixations in the supplemental material. Biased learning for near trials relative to control stimuli occurred. Participants were not explicitly searching for staircases as they do for threatening stimuli in paired or oddball designs (Blanchette, 2006; Fox et al., 2007 LoBue & DeLoache, 2008; LoBue et al., 2014; Öhman et al., 2001). Staircases were a salient but incidental content of the real-world scenes that influenced learning to search within them. Effects on the initial presentation were about search and identification of targets rather than the use of scene gist to direct the initial saccade (cf. Reynolds et al., 2009). The prepotency of staircases does not facilitate finding or processing targets on the initial presentation. Rather we suggest the presence of staircase slant facilitates search near staircase location initially, both in the first presentation of a novel staircase scene and on subsequent encounters, as a result of an enhanced learning potential because of its prepotency as a stimulus.

3.5.4 Suggestions for further research

Although we have interpreted the initial saccade in terms of orienting, no indices of orienting were included beyond eye movements. One potential candidate to be included in future research would be the event related potential (ERP) called the P300 (Donchin, 1981; Friedman et al., 2001; Simola et al., 2013). This positive going wave recorded from scalp electrodes has been linked to orienting in that it is reliably elicited by relatively infrequent events that are task-relevant in oddball paradigms (Donchin, 1981; Friedman et al., 2001); infrequent events would be those occurring on 20% of trials. Even when stimuli are not explicitly task-relevant, they may elicit a P300 when novel (Donchin, 1981). We suspect that prepotency would render all staircase-stimuli as salient and targets might not be required. A stimulus block that contained 20% of staircases, with the remainder non-staircase stimuli, would be informative about the category of novel staircases. For their detection, ERPs are averaged over trials, at least 15, and a minimum of 70 stimuli per block would be required (Friedman et al., 2001). Larger magnitude P300s occur for more important stimuli (Donchin, 1981). A formal comparison including the number of steps in the staircase as a design feature would require twice the number of trials.

3.6 Conclusion

Novel staircases in real-world scenes preferentially drew search to their location and biased cued learning of search when repeated. This prepotency accrues from prior experience. Staircases are salient stimuli to cognitive processes that manage locomotor resources.

3.7 Acknowledgements

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3.9 Supplemental Material

3.9.1 Introduction

In the experiments by Rosemeyer and co-workers (submitted 2020), participants searched real-world scenes for a target in each of 3 stimulus categories: target location near a staircase, far from a staircase, and in control scenes without a staircase. Half of the participants saw the same 18 scenes repeated across nine blocks to test for contextual cueing of visual search (Brockmole & Henderson, 2006a, 2006b). More rapid learning occured for repeated targets located near staircases (slope -101 ms, 95% CI [-109.2, -92.2]) compared to targets farther from staircases (-82 ms, 95% CI [-91.0, -73.5]), and targets in scenes without staircases (-79 ms, 95% CI [-87.5, -70.3]).

In a follow-up experiment, target locations were changed in the final block so that near-staircase stimuli were now located farther from staircases and vice versa. Targets moved farther from staircases were disadvantaged (+1037 ms, 95% CI [+815.5, +1258.5]) relative to control stimuli (+802 ms, 95% CI [+609.9, +994.1]) whereas targets moved closer to a staircase were at a relative advantage (+309 ms, 95% CI [+126.7, +491.3]). Greater contextual cueing for targets near staircases, and reduced disruption of search when targets were moved closer to staircases in the change block, triangulate on the proposal for a prepotency of staircase slants as salient stimuli. There appears to be a consistent search bias that facilitates learning of target-context associations near staircases (Rosemeyer et al., submitted 2020).

For the repeated blocks of stimuli, we predicted more rapid learning near staircases compared to the other stimulus categories, visible in a comparably lower number of fixations required to find targets near staircases; this would be consistent with a search bias towards staircase slant, reflecting previous findings with response latencies analysed earlier (Rosemeyer et al., submitted 2020). To test this prediction, we report here learning over the first eight blocks to replicate the omnibus analyses in the earlier paper. For the change block (block 9) in the second experiment, we predicted an ordering of disruption of fixations, as found previously, such that targets moved near staircases would be disrupted less than control stimuli, whereas targets moved away from staircases would be at a disadvantage relative to control scenes.

3.9.2 Methods

Roughly half of the participants (total *N* = 118) saw six pictures of each category repeated nine times (repeated condition) and another half of the participants saw 18 novel stimuli in each of the nine blocks (novel condition). In repeated presentations, target locations within specific scenes remained the same for all participants (*N* = 64) across the first eight blocks. Target locations within repeated scenes were changed for 27 participants in the ninth block, whilst the other 37 participants saw the targets in the known location repeated a ninth time. For the change in target locations in the ninth block, targets that were previously close to a staircase were now placed farther from the staircase and stimuli of the far category now fulfilled criteria for the near category. Target identity (T or L) changed, both letters being equiprobable. After one third and two thirds of blocks, participants took a short break.

The mixed design included the between-subjects factor of trial type (novel vs. repeated trials) as well as the within-subject factors of block (1-8) and stimulus category (near, far, building). The blocks were balanced for explicit stimulus difficulty within and across stimulus categories. Every block contained 18 scenes. These scenes repeated in the repeated condition and were replaced by novel ones after each presentation in the novel condition. The order of presentation for stimuli was counterbalanced using an 18 x 18 Latin square (for more details on the procedure see Rosemeyer et al., submitted 2020). This order was reversed for half of the participants.

All number of fixations values were natural log transformed. Slope values were back-transformed using a pooled mean across stimulus categories.

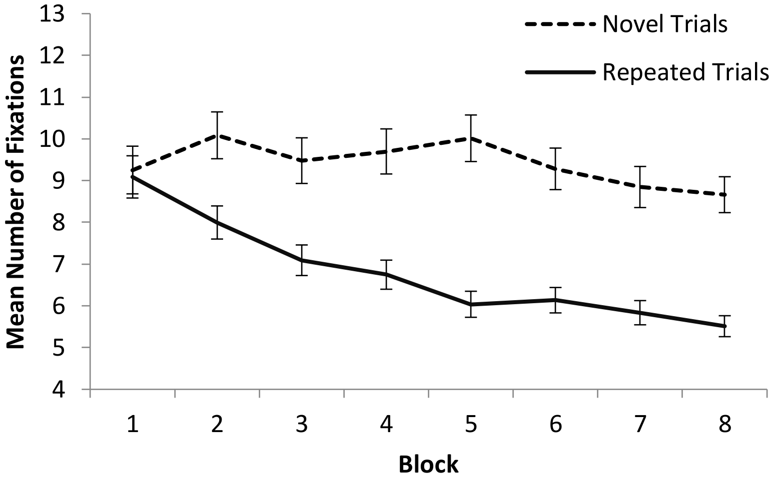
3.9.3 Results

3.9.3.1 Learning in number of fixations

A mixed methods ANOVA ($N = 118$) compared learning in novel and repeated trials (trial type) across the first eight blocks (block). Learning in novel and repeated blocks is shown in figure 3.1. There were main effects of trial type, $F(1, 116) = 124.72$, $p < .001$, $\eta_p^2 = .518$, block, $F(6, 691) = 66.14$, $p < .001$, $\eta_p^2 = .363$, and an interaction between the two, $F(6, 691) = 40.32$, $p < .001$, $\eta_p^2 = .258$. The interaction was explained by the linear (70%, $p < .001$) and quadratic polynomials (22%, $p < .001$). For novel trials alone ($N = 54$), there was learning across blocks, $F(5, 297) = 6.35$, $p < .001$, $\eta_p^2 = .107$, that was accounted for by the linear (38%, $p = .001$) and quadratic polynomials (37%, $p < .001$). To compare learning trends, linear regression analyses for each participant ($N = 118$) over blocks were conducted to estimate the slope across blocks. Analysis revealed steeper learning slopes across repeated blocks, -0.51 fixations, 95% confidence intervals (CI) [-0.6, -0.5], compared to novel blocks, -0.10 fixations, 95% CI [-0.2, -0.04], $t(96) = 10.97$, $p < .001$, $d = 2.24$.

Figure 3.1

Mean Number of Fixations in Novel and Repeated Trials across Blocks 1-8

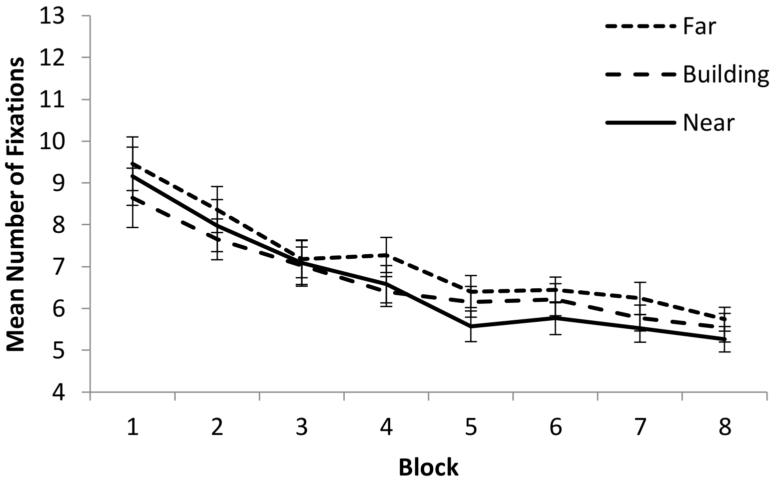


To compare learning trends across the eight blocks between the three stimulus categories (near, far, building), only participants of the repeated condition were included (*N* = 64; 30 F, 34 M; mean age 20.05 years, *SD* = 1.00).

A repeated ANOVA with the within-subjects factors stimulus category (near, far, building) and block (1-8) revealed main effects of block, *F*(5, 322) = 165.80, $p < .001$, $\eta_p^2 = .725$, stimulus category, *F*(2, 126) = 15.39, $p < .001$, $\eta_p^2 = .196$, and an interaction of the two, *F*(11, 669) = 2.16, $p = .016$, $\eta_p^2 = .033$. Figure 3.2 depicts the differential learning in number of fixations of repeated near, far, and building stimuli. Most variance across blocks was explained by the linear polynomial in all stimulus categories, near (91%, $\eta_p^2 = .473$; quadratic 7%, $\eta_p^2 = .035$), far (91%, $\eta_p^2 = .428$; quadratic 5%, $\eta_p^2 = .021$), and building (92%, $\eta_p^2 = .380$; quadratic 5%, $\eta_p^2 = .022$). Follow-up linear regression analyses per participant (*N* = 64) were conducted for each stimulus category across the eight blocks. A repeated ANOVA confirmed differing learning rates between stimulus categories, *F*(2, 126) = 5.03, $p = .008$, $\eta_p^2 = .074$. Descriptively, near stimuli were learnt most rapidly across blocks with a slope of -0.50 fixations, 95% CI [-0.6, -0.4], followed by far, -0.42 fixations, 95% CI [-0.5, -0.4] and building, -0.38 fixations, 95% CI [-0.4, -0.3]. *T*-tests confirmed a steeper learning curve for near stimuli compared to building stimuli, *t*(63) = 2.87, $p = .006$, $d = 0.36$. After Bonferroni correction, there were no differences in learning slopes between near and far stimuli, *t*(63) = 2.11, $p = .039$, $d = 0.26$, or far and building stimuli, *t*(63) = 1.07, $p = .291$, $d = 0.13$.

Figure 3.2

Mean Number of Fixations for Stimulus Categories Near, Far, and Building across Blocks 1-8



A main effect of stimulus category, averaged across the first eight blocks of repeated trials (N = 64), revealed that both near [M = 6.50 fixations, SE = 0.17 fixations; $t(63) = 4.76$, $p < .001$, d = 0.60] and building targets [M = 6.61 fixations, SE = 0.16 fixations; $t(63) = 4.95$, $p < .001$, d = 0.62] had been found with fewer fixations than far targets (M = 7.05 fixations, SE = 0.15 fixations).

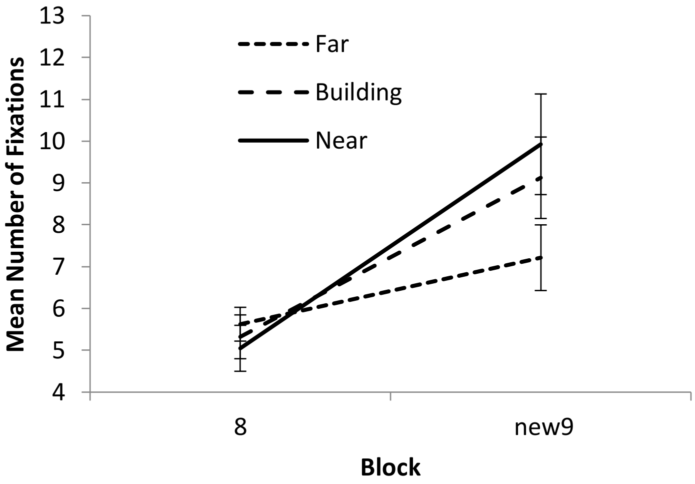
3.9.3.2 Change blocks in number of fixations

In this next section, we report findings related to the change in target locations in the 9th block. Only participants who had seen the same stimuli repeatedly and for whom target positions had changed in the ninth block, N = 27, were included in the following analyses.

A repeated ANOVA compared the mean number of fixations until a response was given across stimulus categories on blocks 8 and 9, on which target positioning was changed relative to staircase location; near staircase targets became targets that were far from the staircase and vice versa. There were main effects of block (8 vs. 9), $F(1, 26) = 156.06$, $p < .001$, $\eta_p^2 = .857$, stimulus category (near, far, building), $F(2, 52) = 5.45$, $p = .007$, $\eta_p^2 = .173$, and an interaction between the two, $F(2, 52) = 16.99$, $p < .001$, $\eta_p^2 = .395$. Figure 3.3 depicts the number of fixations for all three stimulus categories in blocks 8 and 9 with changed target locations. For block 8, there were no differences in number of fixations between stimulus categories (all $p > .026$; Bonferroni corrected significance level: $p = .0167$).

Figure 3.3

Mean number of fixations on blocks 8 and 9 for Stimulus Categories Near, Far, and Building



Note. On block 8, targets were presented in learnt locations for the eighth time, on block new9, targets were presented in novel locations within the same scenes.

To compare changes between blocks 8 and 9 within each stimulus category, we calculated change scores and compared these using follow-up *t*-tests. Former far-staircase scenes required fewer additional fixations after targets were moved closer to the staircases (*M* = +1.77 fixations, *SE* = 0.41 fixations) than former near-staircase stimuli, where targets were moved away from staircases [*M* = +5.15 fixations, *SE* = 0.58 fixations, *t*(26) = 5.94, *p* < .001, *d* = 1.14], and building stimuli [*M* = +3.96 fixations, *SE* = 0.41 fixations, *t*(26) = 4.33, *p* < .001, *d* = 0.83]. There were no statistical differences between former near and control stimuli after Bonferroni correction [*t*(26) = 1.62, *p* = .117, *d* = 0.31].

3.9.4 Discussion

Learning across the first eight blocks replicated the steeper learning curve for repeated trials, compared to novel trials, confirming contextual cueing of search for fixations (cf. Rosemeyer et al., submitted 2020; Chun & Jiang, 1998). Descriptively, the number of fixations replicated the more rapid learning for locations with near-staircase stimuli compared to the other categories (cf. Rosemeyer et al., submitted 2020). Nonetheless, only learning in near and control stimuli differed statistically. When target positioning was changed relative to staircase location in the final block, targets moved closer to the staircase were the least disadvantaged for additional fixations, as has been reported for response latencies (Rosemeyer et al., submitted 2020).

3.9.4.1 Learning in fixations

The steeper slope across the first eight blocks for fixations in repeated real-world scenes, compared to novel scenes, confirmed the contextual cueing of search observed previously with response latencies (Brockmole & Henderson, 2006b; Chun & Jiang, 1998; Rosemeyer et al., submitted 2020). For repeated scenes, learning in each stimulus category was primarily linear across blocks (all > 90%), consistent with response latency. Descriptively, learning slopes were steeper for near (-0.50 fixations) compared to both far (-0.42 fixations) and building (-0.38 fixations) stimuli, as was the case with response latency data previously reported (Rosemeyer et al., submitted 2020). Here, only slopes for near stimuli were steeper, statistically, than building stimuli after Bonferroni correction. This finding is broadly consistent with a search advantage with contextual cueing for near-staircase stimuli, indexed by fewer fixations as opposed to shorter search times (Rosemeyer et al., submitted 2020). Additionally, averaged number of fixations across the first eight blocks revealed that far trials differed from near and building trials, echoing the far-trial disadvantage on the initial presentation reported in the main text of the paper.

The number of fixations and saccades in visual search are strongly correlated with response latency, more so with increasing task difficulty (Murata & Furukawa, 2005; Scialfa et al., 1994; Young & Hulleman, 2012). Nevertheless, differences in learning between near and far categories, as well as differences in responses to changed target positions between near and building categories, were statistically significant only with response latencies. Since differences between the three categories appear similar with both measures, differences in significance may be due to a greater degree of precision in a measurement based on milliseconds compared to a more discreet number of fixations.

Changed target locations

For the change block, the stimuli themselves were almost identical; only target locations changed. As a result, only the task had novelty. For the change in locations, targets moved towards a location remote from staircases produced the greatest increase in number of fixations (+5.15) followed by control scenes (+3.96), with targets moved closer to the staircases the least affected (+1.77). Descriptively, we 'replicated' the ordered relationship for the increase in fixations relative to controls, predicted from previously reported increases in response latencies (Rosemeyer et al., submitted 2020). The advantage for targets close to a staircase is consistent with a search bias towards staircase location in real-world scenes. As with response latency, targets moved closer to staircases were advantaged relative to targets moved away from staircases.

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Chapter four

Chapter three provided evidence of an early search bias towards staircase location that was stronger for staircases with a greater number of steps. This may be one mechanism by which learning of scene content near staircases was enhanced, as reported in chapter two. Learning in chapter two was, however, more gradual than learning reported from previous research of contextual cueing with natural scenes (e.g., Brockmole & Henderson, 2006b). The slower learning in our experiments may have been due to a larger number of repeated scenes and a greater inter-stimulus similarity. The study presented in this chapter aimed to replicate the differential learning observed in chapter two and to compare learning rates of stimuli that were similar, the ones used in previous experiments, to learning rates of more distinct stimuli. Additionally, testing spanned two testing sessions and target locations were changed for half of the participants within- and for half of the participants between sessions. Comparable interruptions within and between learning episodes would confirm a strong role of episodic memory in the learning processes reported in this thesis.

Paper 3

Where the staircase is and where it wasn't;

within- and between-session cueing by scenes with staircases

Rosemeyer, M., Jenkinson, N., & Eves, F. F. (2020). *[Manuscript submitted for publication]*

4 *Where the staircase is and where it wasn't;*

within- and between-session cueing by scenes with staircases

4.1 Abstract

The benefit for contextual cueing of locations in real-world scenes may reflect episodic memory (Wolfe et al., 2011); e.g., repetition of the same target location in a 2nd block benefits from memory of the 1st episode. This study extended previous findings by comparing effects of repetition within a train of stimuli with repetition in a subsequent session 24 hours later. In addition, the study assessed whether a more distinctive range of real-world scenes could produce the more typical negatively accelerated function with repetition (cf. Brockmole & Henderson, 2006b), as opposed to the almost entirely linear learning found in a recent study by our group. In the current research, participants (*N* = 40) searched for letter targets in 18 similar real-world scenes (scenes of buildings with and without staircases) and 18 more distinct scenes (including scene categories of city, park, mountain, home). After eight or nine repeated blocks, a probe in which target locations changed in the subsequent block tested episodic cueing. This change occurred within the first testing session, after eight blocks, or at the beginning of the second session 24 hours later, after nine blocks. Changes to target locations within and between sessions had similar effects. Scene distinctiveness impeded search when novel but, as predicted, facilitated learning across blocks relative to similar scenes. The study replicated more rapid learning of target locations near staircases compared to locations in control stimuli. Search times were most disrupted when targets were moved away from a staircase and least so when moved closer to a staircase. The research confirms that an episode within a train of stimuli was equivalent to an experimental episode occurring 24 hours later.

4.2 Introduction

Habits have been described as automatic behaviours linked to the contexts within which they occur (Lally et al., 2010; Orbell & Verplanken, 2010; Oulette & Wood, 1998; Wood & Rünger, 2016). The majority of pedestrians in shopping malls, 92.4%, avoid stair climbing when an alternative means of ascent is available (Eves, 2014, 2020). Avoidance of stairs is a habit, linked to the contextual cue of a staircase, that helps conserve limited energetic resources for pedestrians (Eves & Puig-Ribera, 2019; Kerr et al., 2001; Webb & Eves, 2007). Contexts can cue search for targets within them. When a target location in a context is repeated, the target is located more rapidly (Chun 2000; Chun & Jiang, 1998; Goujon et al., 2015). Most of this research on contextual cueing of search has employed targets embedded in meaningless arrays of similar elements; learning with meaningless arrays was implicit and based on local features that surrounded the target (Chun, 2000; Olson & Chun, 2002; see also Goujon et al., 2015). Real-world scenes can also cue search with repetition (Brockmole & Henderson, 2006a, 2006b; Henderson, 2017). Here, learning had an explicit component and was initially based on global scene features (Brockmole et al., 2006; Brockmole & Henderson, 2006a; Henderson, 2017). Cueing can be independent of semantics; complex scenes can provide unique visual cues for search that are meaningless (Goujon et al., 2012). For any habit associated with real-world contexts, potential cueing by real-world scenes is of more relevance than that by letter arrays, due to real-world contexts' ecological viability.

This paper is part of a series investigating search biased by staircases, a key feature available in the gist of a context where stair climbing is avoided. Contextual cueing was tested with scenes in which staircases were content that was incidental to the letter search task (Rosemeyer et al., submitted 2020a, 2020b). The staircases were presented face-on, the orientation seen by a pedestrian on approach. Three equiprobable categories of scenes were used: targets *near* staircases, targets *far* from staircases, and targets in scenes of buildings without staircases. With repetitions, search near staircases was facilitated relative to the other categories. In a second experiment target locations were changed relative to staircase location in the final block. There was an ordered statistical outcome across categories. Searches for targets moved away from a staircase were more affected than those in building control scenes, which in turn were more disrupted than searches for targets moved closer to a staircase.

This paper investigates two main questions about contextual cueing of search in staircase scenes. Primarily linear learning functions over repeated blocks (Rosemeyer et al., submitted 2020a) contrasted with the asymptotic improvement in performance in the research on which it was based (Brockmole & Henderson, 2006b; Henderson, 2017). Some discrepancy in the shape of the learning function could result from differences in the distinctiveness of the real-world scenes. A relatively uniform collection of scenes, i.e., pictures of buildings without staircases and pictures of staircases that also included buildings, may be more difficult to learn than the broader range of environmental categories employed by Brockmole and Henderson (2006b). In addition, longer response latencies in the initial block of the original research, compared to the replication (Rosemeyer et al., submitted 2020a), might be one reason for the more negatively accelerated function of explicit learning. For the new experiment, scenes similar to the ones used by Brockmole and Henderson, covered a more distinct range of environments: city, park, mountain, and home (cf. Tversky & Hemenway, 1983). We formally compared cueing by distinct scenes with the combined staircase and control ones of the original report. We predicted more negatively accelerated functions for distinct stimuli relative to our similar ones. As interest was in cueing over repeated scenes, non-repeated scenes were not used.

For contextual cueing by real-world scenes, a distinction between semantic and episodic cueing has been made. Võ & Wolfe (2013) used two blocks of stimuli in which participants searched for 15 different named objects designated as targets. When target location was invariant across the two blocks, memory for each episode within the experiment developed such that successful search latencies were reduced in the second block. In contrast, semantic memory may be required to search for different objects within repetitions of the same scene in the first block (Võ & Wolfe, 2013). In the latter case, minimal search benefits of scene repetition were reported; repetition of the scene alone did not assist search for different objects within it unless their location was anomalous (Võ & Wolfe, 2012, 2013; Wolfe et al., 2011).

Within this framework, more effective cueing for targets near staircases represents memory for episodes within an experiment. This paper contrasted cueing of search within an experimental episode with potential effects of cueing between episodes. Memory retrieval for a stimulus within a continuous train of stimuli may not be the same as memory retrieval for that stimulus within a different episode of the participant's life 24 hours later (Tulving, 1984, 2005). Habitual behaviours, particularly health related ones, are often operationalised as episodes in life that are separated in time from previous occurrences; habit development research entails single daily repetitions of the context (Eves & Puig-Ribera, 2019; Judah et al., 2013; Lally et al., 2010; Orbell & Verplanken, 2010; Tolman & Honzick, 1930).

We used change in target location to probe for differences between life episodes. For one group, the first and second episodes of change occurred within one experimental session, whereas for the other group the second episode occurred 24 hours later. In the second experiment reported previously (Rosemeyer et al., submitted 2020a), when target locations were changed in the final block of trials, targets moved away from staircases were disadvantaged relative to control scenes, whereas targets moved closer were at an advantage. Here, we tested this differential disruption for relocation between experimental sessions. Disruption by change at the end of the first session was compared with disruption by change at the start of a second session 24 hours later. The unique experimental episode, a relocation of the target, was tested across sessions that were temporally separated episodes of the participant's life. Episodic cueing predicts equivalent effects of change for both these probes.

4.3 Methods

4.3.1 Participants

Forty-three undergraduate and postgraduate students from the University of Birmingham (21 F, 22 M; mean age 24.47 years, *SD* = 5.44) participated in this research study. Three participants were excluded, two of them did not turn up for the second session and one had elongated response times (+~1500 ms on average). All participants provided informed consent and were paid £20 for their participation.

4.3.2 Stimuli

This experiment used 18 similar real-world stimuli, the same scenes as repeated in Rosemeyer and colleagues (submitted 2020a), and 18 distinct ones (for examples see figure 4.1 below). The 18 distinct stimuli consisted of indoor and outdoor scenes: 2x a castle on a hill, 2x a living room, 2x a kitchen, 2x a miniature building, 2x a park, 2x a desert, 2x a bridge, 2x a statue, 2x a motorcycle. In contrast to the similar scenes, these scenes were not from the area of Birmingham and they were taken from different viewing angles. One target letter, T or L (light grey; Arial font size 18) was edited into every scene using GIMP (Kimball et al., 2013, version 2.8.10, www.gimp.org). The similar stimuli consisted of 12 urban outdoor scenes with staircases. In six of them, a target letter was positioned close to the staircase ('near' category) and in the other six it was located farther from the staircase ('far' category). The other six similar scenes contained buildings without visible slant ('building' control category). Staircases took up no more than 20% of the scene space and had at least nine steps. All staircases were oriented towards the viewer and were presented on the left and right side in the scenes with equal probability. To reduce confounding effects of their presence (Foulsham et al., 2011), people were excluded from scenes. Scenes were similar in complexity, with target locations between the three stimulus categories balanced for centrality, side and height within images. Targets were positioned evenly across the screen, using a grid with 6 x 8 squares (1024 x 768 – width of 128 pixels per square). This grid was also used to ensure target locations 'far from staircases' had a distance of at least 2 - 3 squares from any staircase (256 - 384 pixels), whereas 'near staircase' locations were no more than one square distant from a staircase (128 pixels). Since near-staircase targets were rarely possible in the upper part of the picture and far targets could not be placed centrally, the two top rows and the two middle columns of the grid were not used for target locations in any category. This target positioning protocol also ensured that participants had to shift their focus of attention from the centre of the screen to fixate a target (cf. Öhman et al., 2001). On average, target locations had a distance of around 375 pixels to the centre of the screen; 512 pixels was the maximal distance sideways from the centre and 384 pixels was the maximum to move up or down.

Figure 4.1

Example Stimuli of the Near, Far, Building, and Distinct Categories

Note. Upper row left to right: examples of similar stimuli of the 'near to staircase' (target letter T is on the left hand side at the bottom of the stairs), 'far from staircase' (target letter T is on the right hand side on the black car), and 'building' (target letter T is to the left of the white car on the kerbstone) stimulus categories. Lower row left to right: three examples of distinct stimuli (target letter T is next to the table on the left-hand side; at the bottom in the shade on the grass; at the foot of the last figurine in the statue). All stimuli were presented in colour.

4.3.3 Procedure

Prior to commencing the experiment, each participant was provided with an information sheet and gave informed written consent. Participants were then instructed to search for small grey letters, L and T, in real-world scenes. As soon as they had found the letter, they were required to press the respective key, L or T, on the keyboard as quickly and as accurately as possible. For explicitness, keyboard positions of L and T were also shown below the monitor. Stimuli were framed by a light grey background on a 24-inch flat ASUS monitor with a resolution of 1920 by 1080, 32-bit colour, and a refresh rate of 60 Hz. Timing and presentation of stimuli were programmed using the E-Prime software (Psychology Software Tools, 2016). Between stimuli, participants were asked to look at a blue fixation circle whilst pressing the space bar to proceed to the next stimulus. If no response was given within 20 seconds, the trial was automatically terminated.

The study was spread across two learning sessions, each consisting of nine learning blocks, with a 24-hour gap between sessions. Each participant was invited back to the second session exactly 24 hours after the first session, to minimise between-session effects of time of day and any circadian rhythm (cf. Smarr et al., 2014). Both sessions began with 18 practice trials, followed by 9 blocks of 36 stimuli: 18 similar ones consisting of 6 near, 6 far, and 6 building stimuli and 18 distinct stimuli. All participants took a quick break after one and two thirds of the experiment (mean total length of one session was 14 min, *SE* = 0.35 min). A short demographic questionnaire was completed after the first session. Each participant was pseudo-randomly allocated to one of two groups (between-subjects factor); both groups were balanced for sex. For the first group, target locations were changed at the end of the first session, in the ninth block. For the second group, the change in target locations was delayed until the first block of the second session, block 10, 24 hours later. Target locations were adjusted so that previously *near* staircase targets were moved to a *far* location and vice-versa. Target locations were also changed for building and distinct stimuli. All targets were moved at least 3.5 squares (448 pixels) from their original position, changing sides, and potentially height, in the image. Target locations were not changed again. Target identity (T/L) changed randomly during repetitions, but at least every third successive presentation of one scene; half of the scenes contained each letter. Stimuli and stimulus-presentation-side (left/right) were both counterbalanced based on an 18 x 18 Latin square. Sums for serial position were very similar for all stimulus categories: near (8773), far (8776), building (8777), and distinct (26324 / 3 = 8774.67). To reduce possible effects of serial position, the order of stimulus presentation was reversed for half of the participants in the first session and then reversed again to 'normal' in the second session.

4.3.4 Design

Using a mixed design, learning – as measured by reduced response time – across 18 blocks (within-subjects factor block) within the three similar stimulus categories (with targets near staircases, far from staircases, and in scenes with buildings) was compared between themselves and with learning within more distinct scenes (within-subjects factor stimulus category). Learning was also compared between groups 1 and 2 (between-subjects factor group). For group 1, target locations were changed in the final block of the first session, whereas for group 2, this change occurred in the first block of the second session.

4.3.5 Data reductions and statistics

All incorrectly (1.3%) and not answered trials (0.5%) were removed prior to data analyses. Complete data for 40 / 43 participants' (20 F, 20 M; mean age 24.00 years, *SD* = 5.25) and 98.2% correctly answered trials were used. Response latencies were reciprocally transformed to correct for positive skew and kurtosis. Slope values were back-transformed via a pooled value across stimulus categories. Bonferroni correction was applied to *t*-tests whenever multiple means were compared and the Greenhouse-Geisser correction was used where sphericity was at risk to be violated (Mauchly test < .05).

4.4 Results

There were no effects of group that impacted on our results (all $p > .08$; all $\eta_p^2 < .061$). Specific comparisons between groups are reported in sections 4.4.2 and 4.4.4.

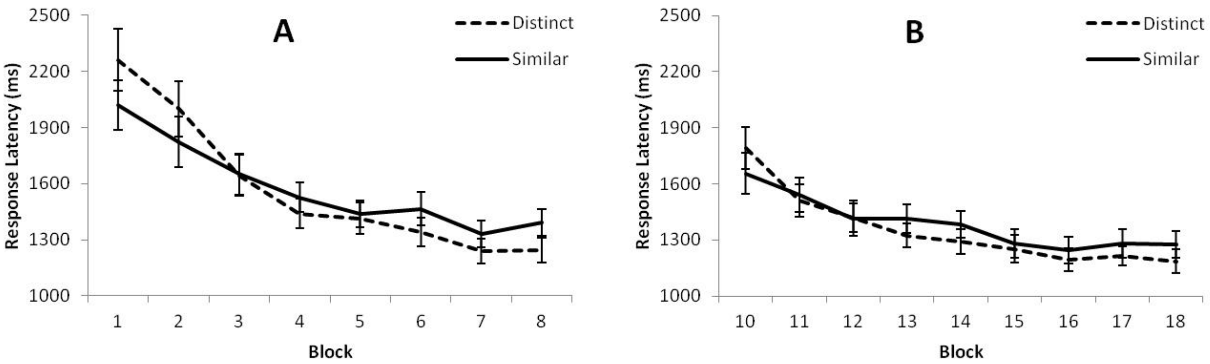
4.4.1 Scene distinctiveness and contextually cued learning

The following analyses compared learning across the first eight blocks of target locations in similar (18) and distinct scenes (18): a repeated ANOVA ($N = 40$) revealed a main effect of block, $F(3, 111) = 178.51$, $p < .001$, $\eta_p^2 = .821$, distinctiveness, $F(1, 39) = 9.08$, $p = .005$, $\eta_p^2 = .189$, and an interaction of block and distinctiveness, $F(7, 273) = 19.97$, $p < .001$, $\eta_p^2 = .339$. For back-transformed learning rates across the first eight blocks of similar and distinct categories see figure 4.2A.

Learning was mostly linear in the similar (89%, $\eta_p^2 = .584$; quadratic 8%, $\eta_p^2 = .049$) and distinct categories (93%, $\eta_p^2 = .768$; quadratic 5%, $\eta_p^2 = .041$). The small magnitude quadratic component was significant for similar and distinct stimuli (both $p < .001$) but did not differ between them, $F(1, 39) = 2.11$, $p = .154$, $\eta_p^2 = .005$. To compare linear learning slopes between stimulus categories, follow-up linear regression analyses were performed for each participant and stimulus category across blocks. These analyses revealed steeper learning slopes for distinct stimuli, -114.78 ms, 95% CI [-125.8, -103.7], compared to similar stimuli, -74.41 ms, 95% CI [-84.5, -64.3], $t(39) = 10.22$, $p < .001$, $d = 1.62$.

Figures 4.2A and B

Learning Original Target Locations in Similar and Distinct Trials across Blocks 1-8 (A) and Learning Changed Target Locations across Blocks 10-18 (B)



Learning rates of similar and distinct stimuli across blocks 10 to 18 are depicted in figure 4.2B. It should be noted that, by block 10, the location of the targets differed in all stimuli relative to the first block in session one. A repeated measures ANOVA (N = 40) revealed a main effect of block, $F(4, 156) = 92.13$, $p < .001$, $\eta_p^2 = .703$, stimulus category, $F(1, 39) = 12.56$, $p = .001$, $\eta_p^2 = .244$, and an interaction of the two, $F(8, 312) = 8.87$, $p < .001$, $\eta_p^2 = .185$. Learning was primarily linear for both, similar (86%, $\eta_p^2 = .462$; quadratic 9%, $\eta_p^2 = .047$) and distinct stimuli (88%, $\eta_p^2 = .607$; quadratic 11%, $\eta_p^2 = .074$), with a significant difference between the categories in the quadratic polynomial over blocks (similar $F(1, 39) = 36.70$, $p < .001$, $\eta_p^2 = .047$; distinct $F(1, 39) = 55.43$, $p < .001$, $\eta_p^2 = .074$), $F(1, 39) = 7.93$, $p = .008$, $\eta_p^2 = .019$. As was found for the first eight blocks, distinct stimuli were learnt more rapidly, -56.17 ms, 95% CI [-63.2, -49.2], than similar stimuli, -40.21 ms, 95% CI [-47.3, -33.1], $t(39) = 5.65$, $p < .001$, $d = 0.89$.

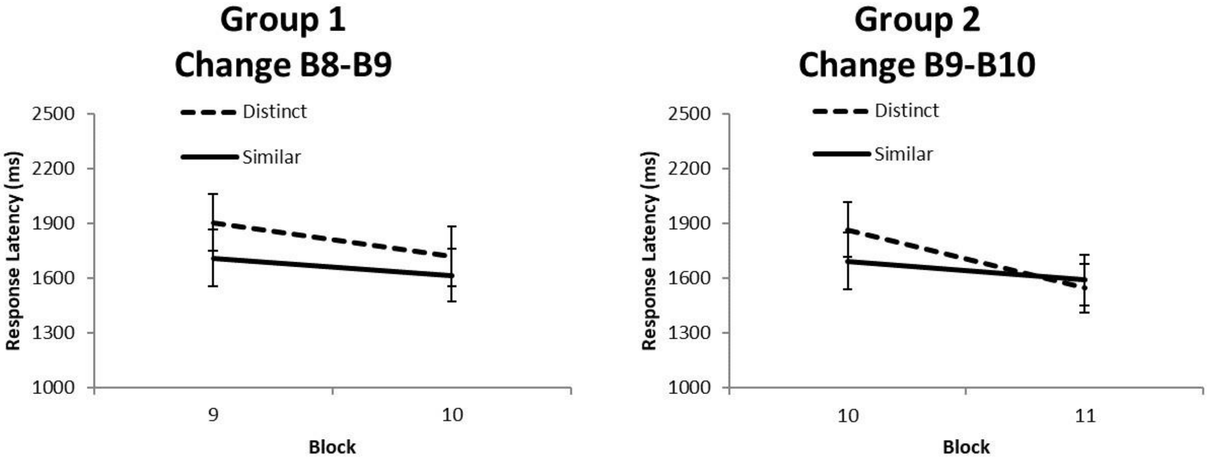
For a direct comparison with Võ & Wolfe (2013), we analysed response latencies for the initial presentation with the subsequent presentation of each target in the first two blocks; distinct and similar stimuli were compared (see figure 4.2). A repeated measures ANOVA (N = 40) revealed a shortening in response times from block 1 to block 2, $F(1, 39) = 40.51$, $p < .001$, $\eta_p^2 = .510$, and shorter response latencies in both blocks for similar relative to distinct stimuli, $F(1, 39) = 29.25$, $p < .001$, $\eta_p^2 = .429$. There was no interaction between the two, $F(1, 39) = 0.06$, $p = .812$, $\eta_p^2 = .001$. For the first block, targets in the distinct category ($M = 2262$ ms, $SE = 85$ ms) were found slower than targets in similar scenes, ($M = 2020$ ms, $SE = 68$ ms), $t(39) = 4.68$, $p < .001$, $d = 0.74$.

4.4.2 Scene distinctiveness and episodic learning

The following analysis compared latencies from the change block with latencies in the subsequent block with changed target locations, between groups (see figure 4.3). A mixed ANOVA with the two within-subjects factors of block (change block, subsequent block) and stimulus category (distinct, similar) and the between-subjects factor of group (group 1 change within the first testing session, group 2 change in the second testing session) was conducted. The analysis revealed main effects of block, $F(1, 38) = 24.91$, $p < .001$, $\eta_p^2 = .396$, and stimulus category, $F(1, 38) = 8.50$, $p = .006$, $\eta_p^2 = .183$, and an interaction between the two, $F(1, 38) = 8.41$, $p = .006$, $\eta_p^2 = .181$. Search for changed target locations in distinctive scenes was slower in the first block, $t(39) = 4.07$, $p < .001$, $d = 0.64$, but, in the subsequent block response times did not differ, $t(39) = 0.70$, $p = .487$, $d = 0.11$. There were no effects of group, all $p > .130$; all $\eta_p^2 < .060$.

Figure 4.3

Response Latencies for Similar and Distinct Trials in the First and Second Block after Changes for Group 1 and Group 2

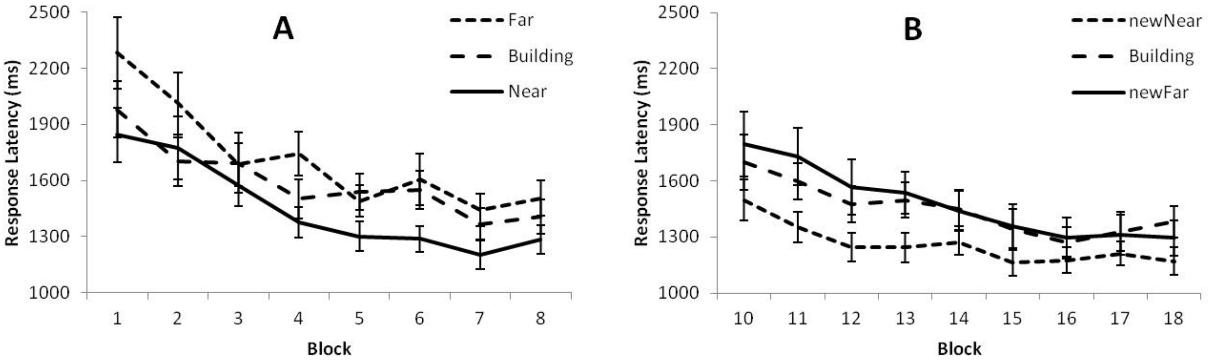


4.4.3 Proximity to staircase and contextually cued learning

Within the first eight blocks, all participants were repeatedly presented with the same scenes and fixed target locations near to a staircase, far from a staircase, and in scenes without a staircase. As there were no deliberate interruptions to learning in these blocks, a repeated measure ANOVA on the first eight blocks compared learning rates between stimulus categories near, far, and building for all forty participants. The ANOVA revealed a main effect of block, $F(4, 172) = 74.26$, $p < .001$, $\eta_p^2 = .656$, a main effect of stimulus category, $F(2, 78) = 65.51$, $p < .001$, $\eta_p^2 = .627$, and an interaction of the two, $F(14, 546) = 5.50$, $p < .001$, $\eta_p^2 = .124$. The differential learning in the stimulus categories across the first eight blocks is shown in figure 4.4A.

Figures 4.4A and B

Learning in Near, Far, and Building Trials across Blocks 1-8 (A) and Learning Changed Target Locations across Blocks 10-18 (B)



Learning rates were best explained by the linear polynomial in all stimulus categories: near (87%, η_p^2 = .489; quadratic 8%, η_p^2 = .046), far (81%, η_p^2 = .386; quadratic 10%, η_p^2 = .048), and building (85%, η_p^2 = .330; quadratic 3%, η_p^2 = .012). From regressions across blocks, near stimuli produced the steepest learning curve, with a slope of -92.2 ms, 95% CI [-106.6, -77.7], followed by far stimuli, -73.5 ms, 95% CI [-87.9, -59.1], and building stimuli, -62.6 ms, 95% CI [-74.2, -50.9]. Although the learning rates differed significantly, $F(2, 78) = 7.99$, $p = .001$, η_p^2 = .170, after Bonferroni correction, only near stimuli were learnt more rapidly than building stimuli, $t(39) = 4.32$, $p < .001$, $d = 0.68$. Near and far stimuli, $t(39) = 2.38$, $p = .023$, $d = 0.38$, as well as far and building stimuli, $t(39) = 1.42$, $p = .162$, $d = 0.23$, did not differ after correction. On average, near targets ($M = 1423$ ms, $SE = 37$ ms) were found quicker than targets in building scenes [$M = 1572$ ms, $SE = 43$ ms; $t(39) = 7.69$, $p < .001$, $d = 1.22$], which, in turn, were found quicker than targets far from staircases [$M = 1684$ ms, $SE = 44$ ms; $t(39) = 4.03$, $p < .001$, $d = 0.64$].

In blocks 10 to 18, all participants were learning the newly changed target locations without further changes. Previous ‘near’ staircase targets were moved away from staircases and are now termed ‘newFar’ stimuli, previous ‘far’ stimuli are named ‘newNear’ stimuli. A repeated ANOVA revealed a main effect of block, *F*(5, 206) = 45.02, $p < .001$, $\eta_p^2 = .536$, a main effect of stimulus category, *F*(2, 78) = 40.36, $p < .001$, $\eta_p^2 = .509$, and an interaction of both, *F*(16, 624) = 2.56, $p = .001$, $\eta_p^2 = .062$. Learning rates in milliseconds are depicted in figure 4.4B.

As in the first eight blocks, learning was best explained by the linear polynomial in all stimulus categories: newFar (95%, $\eta_p^2 = .370$; quadratic 3%, $\eta_p^2 = .013$), newNear (71%, $\eta_p^2 = .236$; quadratic 16%, $\eta_p^2 = .052$), and building (76%, $\eta_p^2 = .237$; quadratic 11%, $\eta_p^2 = .033$). Follow-up linear regression analyses showed that newFar stimuli were learnt more rapidly, -52.85 ms, 95% CI [-63.3, -42.4], than both newNear, -34.93 ms, 95% CI [-43.1, -26.7], *t*(39) = 3.93, $p < .001$, $d = 0.62$, and building stimuli, -36.84 ms, 95% CI [-45.3, -28.4], *t*(39) = 3.35, $p = .002$, $d = 0.53$, *F*(2, 78) = 8.87, $p < .001$, $\eta_p^2 = .185$. As is apparent in the figure, target detection times averaged across blocks 10 to 18 were shorter for the newNear category ($M = 1252$ ms, $SE = 32$ ms) compared to both other categories, newFar [$M = 1462$ ms, $SE = 51$ ms; *t*(39) = 8.21, $p < .001$, $d = 1.30$] and building [$M = 1439$ ms, $SE = 40$ ms; *t*(39) = 7.22, $p < .001$, $d = 1.14$], *F*(2, 78) = 40.36, $p < .001$, $\eta_p^2 = .509$.

A repeated measures ANOVA ($N = 40$) revealed savings in response times on block 2 relative to block 1, *F*(1, 39) = 19.21, $p < .001$, $\eta_p^2 = .330$, and, on both blocks, shorter search times for near and building stimuli, compared to far stimuli, *F*(2, 78) = 19.71, $p < .001$, $\eta_p^2 = .336$. Furthermore, there was suggestive evidence of less shortening in response times, from block 1 to block 2, in near compared to building trials, *F*(2, 78) = 3.15, $p = .048$, $\eta_p^2 = .075$. On the first block, there was an ordered relationship, such that targets of the near category were found quickest ($M = 1845$ ms, $SE = 74$ ms), followed by building trials [$M = 1980$ ms, $SE = 77$ ms; *t*(39) = 2.09, $p = .044$, $d = 0.33$], and responding was slowest for far trials [$M = 2283$ ms, $SE = 98$ ms; *t*(39) = 5.30, $p < .001$, $d = 0.84$].

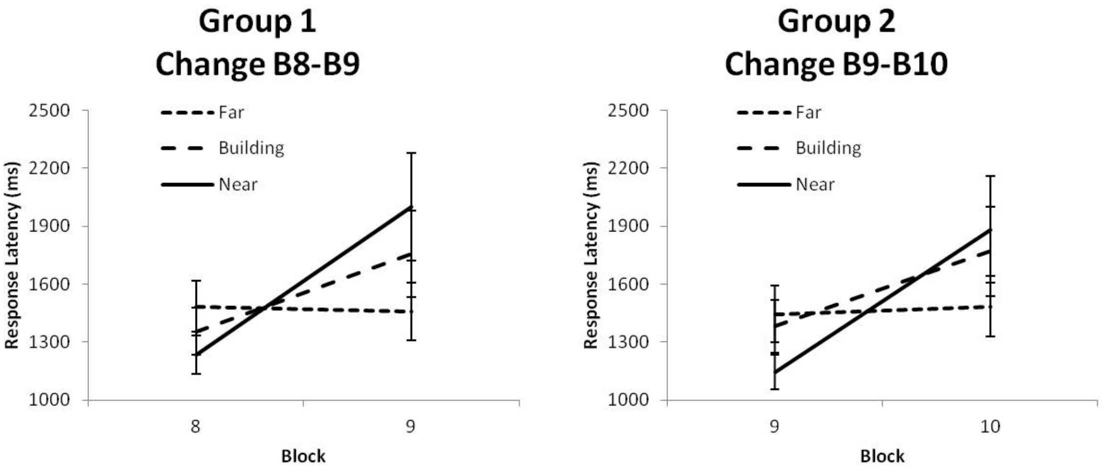
4.4.4 Proximity to staircase and change blocks

An omnibus ANOVA compared response latencies before and after the change of target locations in group 1 (change on block 9; $N = 20$) and in group 2 (change on block 10; $N = 20$). A mixed ANOVA with the two within-subjects factors block (8, 9, 10) and stimulus category (near, far, building), and the between-subjects factor group (1, 2) revealed a main effect of block, *F*(2, 76) = 18.79, *p* < .001, η_p^2 = .331, an interaction between block and stimulus category, *F*(4, 152) = 12.54, *p* < .001, η_p^2 = .248, and a three-way interaction that also included group *F*(4, 152) = 13.74, *p* < .001, η_p^2 = .266.

To clarify the three-way interaction, a follow-up analysis compared the final repeated block with the subsequent change block between groups. Figure 4.5 depicts back-transformed response latencies for groups 1 and 2 before and after the change in target locations, i.e., blocks 8, 9 and 9, 10 respectively, for the three stimulus categories. The analysis revealed a main effect of block, *F*(1, 38) = 61.89, *p* < .001, η_p^2 = .620 and an interaction between block and stimulus category, *F*(2, 76) = 45.47, *p* < .001, η_p^2 = .545. Importantly, there were no effects involving group (all *p* > .188; all η_p^2 < .045).

Figure 4.5

Response Latencies for Near, Far, and Building Trials Before and After Changes for Group 1 and Group 2



To further inspect the differential effects of changes in target locations, we computed change scores, based on response latencies before and after the change of locations, for each stimulus category. These were then compared in an ANOVA with the within-subjects factor of stimulus category (near, far, building) and the between-subjects factor of group (1, 2). There was a main effect of stimulus category, $F(2, 76) = 45.47$, $p < .001$, $\eta_p^2 = .545$, but no effect or interaction with group (all $p > .678$). Originally near trials were most affected (M = +864 ms, SE = 87 ms), followed by building trials [M = +454 ms, SE = 100 ms, $t(39) = 4.66$, $p < .001$, $d = 0.74$] which in turn were more affected than far trials [M = +18 ms, SE = 71 ms, $t(39) = 4.44$, $p < .001$, $d = 0.70$].

4.5 Discussion

4.5.1 Effects of stimulus distinctness

Typically, learning functions are negatively accelerated, as was reported for contextual cueing with real-world scenes (Brockmole & Henderson, 2006b; Henderson, 2017). In our earlier study, primarily linear learning functions, 90% - 96%, contrasted with asymptotic improvements within five to seven repetitions in the research on which it was based (Rosemeyer et al., submitted 2020a). Formal comparison of distinctiveness confirmed steeper learning for distinct stimuli across blocks than more similar ones. This observation was true for both the initial session and the second session where the target location had been changed. Hypothesized effects of stimulus distinctness on the shape of the learning function were not supported. Both, distinct and similar stimuli produced primarily linear functions across the first eight blocks, with no differences between them in the quadratic component.

Analysis of the initial block confirmed longer response latencies for distinct stimuli (M = 2262 ms, 95% CI [2096, 2429]) relative to similar ones (M = 2020 ms, 95% CI [1887, 2153]). Nonetheless, latencies were shorter than those reported by Brockmole and Henderson from their first block (2006b, figure 1; M = 3890 ms, 95% CI [3340, 4440]). This difference in initial latencies suggests greater initial difficulty for the distinct stimuli used by Brockmole and Henderson (2006b). Longer initial latencies allow reductions with repetition that could result in more typical negatively accelerated functions.

Formal comparison between blocks 1 and 2 that match Võ and Wolfe's analysis did not reveal any differential effects of scene distinctiveness with one repetition in the first session. Distinct scenes were still at a disadvantage relative to similar ones in the second block whereas one might have expected repetition to remove effects of distinctiveness if only target location was relevant. Differences in design from Võ and Wolfe (2013) can explain this discrepancy: participants in Võ and Wolfe (2013) searched 15 repetitions of the same scene for different scene objects before any repetition of a specific object location in the second block. In our study, 36 different scenes occurred in block 1 and, hence, block 2 was the first repetition of target location in *any* scene. The saving of approximately 200 ms with repetition was considerably less than the 455 ms saving for consistent locations in Võ and Wolfe (2013). The change block was also relevant here. The change was the 9th or 10th repetition of any scene, sufficient for a more elaborated representation than initially in session 1. While effects of change were greater with distinct stimuli, differences between distinctive and similar scenes were absent in the second block of change trials. This pattern of differences between blocks 1 and 2 better matches Võ and Wolfe's conclusion that finding a target creates a binding between the scene and the target location (Võ & Wolfe, 2012, 2013). The more elaborate representation that results from multiple repetitions may assist this binding process.

Here, distinctiveness of the scenes impeded search initially, and when target location changed in the second session, relative to similar scenes. It is unlikely that similar scenes were advantaged; increases in the number of exemplars of a category impaired explicit performance (Konkle et al., 2010). Distinctive scenes within a block appear to impede search when novel in that block. In contrast, their distinctiveness facilitated learning within both experimental sessions, reflecting the fact that the relative uniqueness of visual stimuli provides a beneficial cue for learning (Goujon et al., 2012).

4.5.2 Contextual cueing within and between sessions

A second aim of this study was to compare searches for changed target locations within and between experimental episodes. Almost identical effects of distinctiveness were found with repetition 24 hours later. Similarly, the probe of changed locations relative to a staircase resulted in equivalent effects within the first session and after 24 hours. High recognition rates have been found for pictorial stimuli (Shepard, 1967; Standing, 1973), even when up to 64 exemplars of each category were employed (Konkle et al., 2010). Concerning between session effects, Shepard (1967) reported correct recognition at 90% a week later and above chance recognition even after 120 days. Nonetheless, the task in the contexts here was to identify a small letter target within a scene. It is unknown whether impressive recognition rates for pictorial stimuli would extend to the identity of a small letter target within them, despite impressive recognition rates for the state of an isolated object (Brady et al., 2008) or its orientation within a complex scene (Hollingworth & Henderson, 2002) . None of these recognition studies required search for a target that might bind location within a scene to its identity (cf. Võ & Wolfe, 2012, 2013; Wolfe et al., 2011). The absence of any differences in the pattern of results within an experimental episode when compared with a subsequent episode 24 hours later confirm the earlier research on cueing of location (Võ & Wolfe, 2012, 2013; Wolfe et al., 2011). Episodes within a train of stimuli appear equivalent to episodes more distant in time as in Tulving's original proposal (Tulving, 1972, 1984).

4.5.3 Replication of biased search towards staircases

One point should be clarified before discussing staircase trials: contextual cueing is explicit with real-world scenes (Brockmole & Henderson, 2006b). For staircase scenes, the target was near the staircase in half of the scenes. A helpful reviewer suggested that an explicit strategy of searching near staircases could produce both biased learning over blocks and facilitated search when targets were moved closer to the staircase in change trials. This explicit strategy was uncommon. When participants in a subsequent study were asked, '*Did you use any specific strategies to find the letters*?', only two out of 78 reported searching stairs first and three others mentioned stairs amongst other scene elements, i.e., railings, cars, bushes, houses (Rosemeyer et al., in preparation 2020c). As only five participants explicitly mentioned staircases it suggests there is not a generalised explicit strategy to search near them. Target locations and reward for task completion were equiprobable between categories. It seems unlikely that a bias to search near to, rather than far from, a staircase would develop associatively when target locations far from staircases were just as probable.

The current study replicated previous findings for response latencies; contextual cueing across the first eight blocks was more successful in near trials compared to building trials, and to a lesser extent far trials (Rosemeyer et al., submitted 2020a). With the smaller sample here, 40 vs. 120, only the difference between near and building controls was statistically reliable. Concerning enhanced learning for targets near staircases, the local features surrounding the target include the salient scene feature of a staircase which might facilitate implicit learning of target location (Chun, 2000; Olson & Chun, 2002). Across both sessions, targets near staircases were found quicker overall than the other two categories, consistent with biased learning of locations near staircases.

Replicated effects of changed target locations also replicated biased search towards staircase location. In both groups, moving targets away from a staircase, increased search latencies, ~+750 ms, whereas search times for targets moved towards a staircase were unaffected, ~+18 ms, a more extreme contrast than found previously (Rosemeyer et al., submitted 2020a). Searches for control stimuli were intermediate between the other categories, ~+400 ms impairment. As noted elsewhere, the contrast between disadvantage for targets moved away from staircases and a relative advantage for targets moved close to a staircase provides triangulation on the proposal for biased search to the location of staircases in real-world scenes that has been replicated here (Rosemeyer et al., submitted 2020a). Staircases provide important environmental signals to cognitive processes that manage energetic resources.

As noted in the introduction, habits are behaviours linked to contexts in which they occur (Orbell & Verplanken, 2010; Oulette & Wood, 1998; Wood & Rünger, 2016). Typically, stair climbing is avoided when there is an alternative method of ascent (Eves, 2014, 2020), and the slant of the staircase provides a cue that can prompt this avoidance (Eves et al., 2014; Taylor-Covill, 2013, chapter 7). Pedestrians minimize the cost of active transport to conserve energetic resources (Croft et al., 2017; Levine & Kotz, 2005; Srinivasan, 2009). We have reasoned elsewhere that repeated experience of staircases during development allows pedestrians to discover a major property of staircases, namely the effort required to climb them that is a 'felt' proxy for their biological cost (Rosemeyer et al., submitted 2020a). This property that immediately follows the perceptual cue of a staircase may allow habitual avoidance to develop in an associative manner to minimize expenditure in adult walking (cf. Strack & Deutsch, 2004). The similarity of memory effects within and between episodes for real-world scenes containing staircases is encouraging. Habits can be characterised as episodes in life that are separated in time from their previous occurrence; single daily repetition of a context is a common feature of habit development (Eves & Puig-Ribera, 2019; Judah et al., 2013; Lally et al., 2010; Orbell & Verplanken, 2010; Tolman & Honzick, 1930). The results here suggest that pictures of real-world contexts related to habits may provide a tool to investigate cues within contexts that prompt habitual behaviour (Gardner et al., 2016; Orbell & Verplanken, 2010; Phillips & Gardner, 2016).

4.5.4 Limitations and future directions

Generalizability of the results may be limited by the choice of specific natural scenes and target locations therein. Here, target locations in near and far categories were not counterbalanced across participants such that part of the differences between the categories could have reflected the scenes themselves. Counterbalancing of near and far targets across the specific scenes would remove this concern. In the research presented in this report, for one group, the change trial occurred after 8 blocks whereas for the other it occurred after 9 blocks. Inspection of figure 4.5, however, does not suggest there were substantial differences created by the extra block of repetition before the change in one group.

We think this search bias by an incidental feature of context is an attentional one. A formal test of attention with matrices containing staircases in an odd one out search could confirm this assumption (e.g., Öhman et al., 2001). Nonetheless, explicit search for staircases may be less able to address the question of bias developed associatively throughout maturation. The design tested contextual cueing in two separate sessions. If researchers were only interested in the effects of the change, the second session could dispense with blocks 11 - 18 without loss.

4.6 Conclusion

Distinct scenes impaired search when novel but facilitated the learning of target locations with repetition, possibly because of the beneficial cue provided by uniqueness. Effects of changes to target locations on response latencies were equivalent within a train of stimuli and when separated by 24 hours. Repetition within a train of stimuli appears equivalent to repetition in a subsequent experimental episode. The bias towards staircase locations in real-world scenes was replicated. Near-staircase stimuli were learnt more rapidly than control stimuli and search was disrupted most when targets were moved away from staircases, with targets moved close to staircases at an advantage relative to control scenes. Staircases represent important environmental cues that assist minimization of the energetic costs of active transport.

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Chapter five

General Discussion

5 General Discussion

The aim of this thesis was an exploration of a potential potency of staircase percepts as environmental cues relevant for prompting resource-saving habitual behaviour. Chapter three investigated early visual search in the presence of staircases as incidental visual scene content. The staircases formed part of the global scene content in contextual cueing experiments; participants were searching for letter targets, not for staircases. The potential for facilitated learning of scene content that was located proximal to, rather than more remote from, or independent of an image of a staircase was explored (chapters two and four). Main findings, strengths, and limitations of our experiments will be discussed below, followed by directions for future research.

5.1 Main findings

5.1.1 A prepotency of staircases and the length of the climb

The second study, presented in this thesis, revealed a bias of initial saccades towards staircase location; crucially this effect was independent of target location.

The influence of staircase location on the direction of the initial saccade supports the notion that the gist of novel staircase scenes can influence eye movement behaviour in a matter of a few hundred milliseconds (e.g., Oliva, 2005), potentially through a mechanism akin to the orienting response (see Fernández-Martin et al., 2017; Sokolov, 1963). Early exogenous attention appears to be attracted by the salient scene feature of a staircase, comparable to what has previously been reported for other threatening and emotionally salient stimuli in paired and odd one out designs (Blanchette, 2006; Calvo & Lang, 2004; Calvo et al., 2008; Fernández-Martin et al., 2017; Fox et al., 2007; LoBue & DeLoache, 2008; Nummenmaa et al., 2006, 2009). The fact that initial saccades *were* on average *biased* towards novel staircases, even though staircases were not a target of visual search in our experiments (cf. Fernández-

Martín et al., 2017; Yorzinski et al., 2014), supports the notion that staircases may indeed have prepotent properties. Staircase slant, costly to energetic resources, has phylogenetic and ontogenetic relevance that may explain the facilitated initial search and learning behaviour, proximal to its location, documented in this thesis.

Surprisingly, biased search towards novel staircases did not lead to quicker responding in near, compared to control trials, even though learning was facilitated for near relative to control stimuli in all chapters. The discrepancy may be due to the fact that the influence of scene gist, that is unpredictive of target location, depends on early, exogenous attention (see Jonides, 1981; Posner, 1980). In a subsequent study, no more than 2 out of 78 participants mentioned staircases when asked for any letter search strategies employed. Searching, finding, identifying, and responding to novel target locations within novel scenes in the first block took, however, around 2 seconds. Hence, effects of novel staircase precepts on reflexive attention allocation may not have become as apparent in overall first block search times or total number of fixations (cf. Reynolds et al., 2009). Instead, effects may be more clearly reflected in directionality of early visual search (e.g., Cheal & Lyon, 1991) and in the differential learning rates (cf. Cook & Mineka, 1989; Donovan et al., 2015; Öhman et al., 1976; Szpiro & Carrasco, 2015; discussed in section 5.1.2).

To further explore the potential of exogenous attention specifically attracted by staircase slant, I suggest a paired design, where two stimuli are presented simultaneously, without being task-relevant, whilst initial eye movements are recorded (see Calvo & Lang, 2004; Calvo et al., 2008; Fernández-Martin et al., 2017; Nummenmaa et al., 2006, 2009). This design would allow formal testing of automatic biases in initial eye movements towards specific stimuli. More, if the perception of staircase slant elicits exogenous shifts of attention, impulsive processing (Strack & Deutsch, 2004) may play a prominent role in the habitual avoidance of staircase slant. Implications are discussed in section 5.3 of this thesis.

The bias in direction of initial search was magnified for staircases with more than 13, compared to less than 14, steps. The number of staircase steps informs the rough outline of the zigzagging surface of a staircase that is included in scene gist, with an immediate effect on perception (cf. Oliva, 2005). A staircase with more steps takes longer to climb, increasing energetic costs and physiological risks involved in a climb. An attentional bias that gains strength in the presence of more costly staircases can efficiently support cognition that facilitates economic, resource-based action (Proffitt, 2006).

5.1.2 Contextual cueing with staircases

In all experiments that tested learning across blocks (chapters two and four), learning was most pronounced near staircases; the difference in learning between near and far stimuli in chapter two was only descriptively evident in the smaller sample tested in chapter four. Averaged across blocks, targets near a staircase were found quickest, followed by control targets, whereas targets located far from staircases were associated with the longest response latencies overall.

Biologically prepotent, i.e., prepared, stimuli have previously been associated with superior learning rates (e.g., Cook & Mineka, 1989; Öhman et al., 1976). The here reported early bias in saccades, reminiscent of the orienting response, towards an experientially prepotent stimulus, may hint at underlying mechanisms. In contextual cued learning with real-world scenes, target locations have been reported to be associated with *global context* initially (Brockmole et al., 2006; Brockmole & Henderson, 2006a). Brockmole and colleagues (2006) defined global context in their experiments as the broad spatial structuring of the scene, an example would be a room with seating furniture. With the aim of expanding on previous research and knowledge, I specifically tested for a potential bias by the gist of natural scene content with staircases on contextually cued learning. The findings are consistent with a view where the gist of staircase scenes biased contextual cueing, without being task relevant. Scene gist can influence attention exogenously, almost instantly (cf. Castelhano & Henderson, 2008; Oliva, 2005). Consistent with our findings, exogenous attention has previously been linked to enhanced perceptual learning (cf.

Donovan et al., 2015; Szpiro & Carrasco, 2015) even when the cue was unrelated to the current task (cf. Carrasco, 2011, p. 1488).

Visual memory in contextual cueing has been found to be supported by semantic and episodic memory (Hollingworth, 2012; Võ & Wolfe, 2013). The fourth chapter reported findings according to which changes in target locations caused equal disturbance whether they happened within or between sessions. Testing sessions were separated by a 24-hour gap. Memory from one temporal episode, a testing session, seemed to be retrieved equally well within and between sessions, pointing to a strong involvement of episodic visual memory. These findings are consistent with strong within- and across-session effects of visual memory that have been reported from previous research: within one testing session scene memories were retained over more than 600 intervening trials (Hollingworth, 2004; Shepard, 1967; Standing, 1973) and with more than 50 exemplars of one category (Konkle et al., 2010). Memory of prior search experience in contextual cueing reliably guided search, even with many intervening trials (e.g., Brockmole & Henderson, 2006b; Võ & Wolfe, 2012), and visual memory preserved scene and object *details* over the course of five and a half hours of picture viewing (Brady et al., 2008; Hollingworth, 2005). Furthermore across-session effects of visual memory were reported after 24-hours (Hollingworth, 2005), one week (Shepard, 1967), a few weeks (Rock & Engelstein, 1959), and even 120 days (Shepard, 1967).

5.1.3 Changed target positions relative to staircase location

Following contextually cued learning, as predicted, relocating targets farther from staircases led to the greatest slowing in response times, in the range of 864-1037 milliseconds (see chapters four and two). When targets were moved nearer to the staircase, response latencies slowed very little (*M* = 309 ms, chapter two) or not at all (*M* = 18 ms, chapter four). Slowing in the control stimulus category was intermediate with 454-802 milliseconds (chapters four and two). Between the experiments reported in chapters two and four, contextually cued learning was more rapid in chapter two with a learning slope for repeated scenes of -87 ms and response latencies of around 1232 ms on block 8, compared to chapter four with a learning slope of -76 ms and response latencies of around 1359 on block 8. On block 8, the difference of 127 ms between experiments roughly equalled the learning across 1.5 learning blocks. Correctly responding to relocated targets took an average of 238 additional milliseconds in chapter two, compared to chapter four (group 1 only). Learning conditions in the two experiments differed by the number of repeated scenes (18 vs 36, chapters two and four) and hence by the length of inter-stimulus repetition intervals.

It seems likely that the larger number of repeated scenes (36 vs. 18) may have slowed learning in chapter four compared to learning in chapter two; the same effect could explain the slower learning observed in chapter two, with 18 repeated scenes, relative to learning in Brockmole and Henderson (2006b) with eight repeated scenes. This notion seems unsupported by research on visual memory, where scene recognition has been reported to be maintained over thousands of trials, even when up to 64 images belonged to one scene category and when 160 different scene categories were studied; only a small decrease of 2% in memory performance was observed when the number of studied images per category was doubled (Konkle et al., 2010). It is conceivable, however, that the more rapid learning of distinct stimuli, and target locations therein, in chapter four may have impaired memory (cf. Melcher & Murphy, 2011) or reduced limited cognitive resources (Baumeister & Alquist, 2009; Christie & Schrater, 2015) for the more effortful learning of target locations in similar scenes.

It seems that learning and slowing in response latencies upon changes in target locations, were more pronounced in chapter two, compared to chapter four. It is reasonable that steeper learning curves may be associated with stronger target-context associations, inhibiting adaptation to changes and increasing the likelihood for eye movements towards old target locations (cf. Manginelli & Pollmann, 2009), thereby slowing the detection of targets in novel locations.

A change in target locations in previous research on contextual cueing increased response latencies only by roughly 170 milliseconds (Magnelli & Pollmann, 2009), 85 milliseconds (Zellin et al., 2014), or 50 milliseconds (Makovski & Jiang, 2010). In Magnelli and Pollmann (2009) this was all the difference there was to response latencies for novel displays. Importantly, the above experiments tested for contextual cueing and search of changed target locations in nondescript arrays of letters and simple shapes. Real-world scenes differ from letter arrays, for example 'in their visual complexity and in semantic richness' (Goujon et al., 2012, p. 1324). Contextual cueing in letter arrays has been found to be implicit (Chun & Jiang, 1998) and focused on local contextual configurations (Brady & Chun, 2007; Jiang & Wagner, 2004; Olson & Chun, 2002), boosting learning of repeated scenes by about 10%. In contrast, contextual cueing effects in real-world scenes are typically much larger, about 68% (Castelhano et al., 2019) and learning was explicit (Brockmole & Henderson, 2006b), eventually (Goujon et al., 2014). More, local and global scene context were relevant (Brockmole & Henderson, 2006a ; Hollingworth, 2006), in degree depending on search time (Brockmole & Henderson, 2006a; Rosenbaum & Jiang, 2013), target location (Castelhano et al., 2019), on the task (Fernandes & Castelhano, 2019), and on the predictiveness of the respective context (Brooks et al., 2010; Rosenbaum & Jiang, 2013).

Clearly, there are major differences between learning in repeated natural scenes and learning in letter arrays. Contextually cued learning and resistance to learning of changed target locations were a fivefold stronger in real-world scenes, compared to the original contextual-cueing contexts. It may be that associations formed in natural scenes are stronger due to the rich semantic nature of scenes, that provide a fruitful basis for episodic memories compared to an empty display filled with 11 rotated shapes and one slightly differently shaped target. Additionally, Zinchenko and co-workers (2020) found an effect of distributed versus focused attention, such that a wider distribution of attention supported responsiveness to changes in target location. Contextual cueing in real-world scenes, compared to cueing with letter arrays, may be more focused towards the semantic scene content, especially when the content includes an energetically costly staircase. Staircases may act as visual cues that can prompt functional habits, such as the avoidance of energetically costly staircase slant. The efficiency of staircases, as salient visual cues signalling threat, may be boosted by prepotent properties, that can elicit an instant orienting of attention (c.f., Fernández-Martin et al., 2017; Nummenmaa et al., 2009), ease associative learning (Cook & Mineka, 1989; Öhman et al., 1975; Öhman & Mineka, 2001; Öhman & Soares, 1993, 1994, 1998; Seligman, 1970, 1971), and resist changing of learnt associations (cf. Öhman et al., 1975, 1976). Importantly, staircases in our experiments were facing participants, as they would when being approached for climbing in real-life situations (cf. preparedness research by Flykt et al., 2007; Hugdahl & Johnsen, 1989) where geographical slant was overestimated, in magnitude relative to the availability of relevant resources (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2014, 2016).

5.1.4 Effects of resources

Surprisingly, findings in chapter two revealed no relationship between perceptual biases and relevant temporary (level of hunger) or longer-term (sex, BMI) resources. In previous research, perception of staircase images was dependent on metabolic resources (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2016). Consistently, perception of staircases and hills was biased to overestimate geographical slant, independently of any intention or opportunity to climb the respective slant (Eves, 2016; Witt et al., 2016). Nevertheless, whilst, in previous research, participants were asked to estimate staircase slant on life-sized displays; in the presented series of experiments, participants were not instructed to pay any attention to staircases. Conversely, participants were asked to search for a target letter L or T, unrelated to staircases that were presented as incidental scene content. A research design aimed at testing early attention allocation to specific stimuli, such an odd one out (e.g., LoBue et al., 2014; Öhman et al., 2001) or a paired design (e.g., Fernández-Martin et al., 2017; Nummenmaa et al., 2009) may be more informative about effects of resources on attentional mechanisms in the perception specifically of staircases. It is a possibility that, in contrast to slant perception, an attentional bias towards staircases is independent of energetic resources. A small-sized effect of resources may have stayed undetected due to our specific student sample (see section 5.2.4).

In sum, our findings are consistent with a developmental view in which visual percepts of staircase slant have become associated with the energetic costs of climbs through a lifetime of learning. This process may have made staircases prepotent stimuli, salient scene features, associated with the effort of climbing, that can efficiently initiate and facilitate associative learning, including learning of a habitual response of avoiding staircase slant. Our findings supported this notion; initial search seemed to be exogenously biased towards novel, task-irrelevant, staircase percepts, in magnitude dependent on anticipated energetic costs of a climb that was indexed by the number of staircase steps. More, learning of target-context associations near staircases was more rapid compared to learning of other associations; adjusting to changes was slowed when the eyes needed to move farther from staircases. This effect was independent of the specific testing session, supporting evidence of episodic memory involved in contextually cued learning and in learning biased by incidental scene content.

5.2 Strengths and Limitations

5.2.1 Research Design

All studies presented in this thesis involved pseudo-randomized controlled designs. Participants were pseudo-randomly allocated to experimental groups (novel vs. repeated in chapters two and three; change within vs. between sessions in chapter four) and effects of experimental manipulations were compared to a control condition with houses as built environment comparable to staircases. Although we used a between-subjects design to compare learning of novel and repeated stimuli in chapter two, chapter four provided a more robust within-subjects comparison, comparable to previous research on contextual cueing with natural scenes (e.g., Brockmole & Henderson, 2006b); stimulus category and learning blocks were always included as within-subject factors and analysed accordingly.

To increase *internal validity*, the certainty with which effects can be assumed to be caused by experimental manipulations (e.g., Orquin & Holmqvist, 2018), all stimulus categories were equiprobable and the order of presentation was balanced across categories. Target placement and definitions of stimulus categories were based on a grid laid across image space (cf. Jiang & Sisk, 2019). Centredness, sidedness, and height of target location, apparent scene complexity, scene saliency (see methods section in chapter three), and explicit stimulus difficulty (rating task, chapter two) were attempted to balance between stimulus categories. Nevertheless, different scenes were used to provide context for cueing between the categories. Introducing the possibility of image features systematically varying with target locations.

The adopted research paradigm was based on research by Brockmole and Henderson (2006a, 2006b). As a novel contribution, we explored the potential of staircase images, as incidental scene content, to influence contextual cueing. Consistent with our prediction, contextual cueing was more rapid when targets were located near staircases rather than anywhere in scenes without staircases.

As was done in previous contextual cueing experiments (e.g., Brockmole & Henderson, 2006b), participants were instructed to search for a target letter L or T within scenes. Some of these scenes accidentally included staircases. This is how it appeared to 97% of participants in a subsequent study, based on responses upon being asked what they thought the experiment was about, whether they used any specific strategies to find the targets, or whether they had any other comments why it was hard or easy to find the targets. Only 6% of participants even mentioned staircases, amongst other items, such as railings, cars, bushes, and houses, that typically appeared in our scenes (Rosemeyer et al., in preparation 2020).

5.2.2 Measurement

All our experiments were conducted in a laboratory environment, where each participant was provided with the same equipment and instructions, to increase *internal validity; this approach inevitably* threatens *external validity*, the generalizability of findings to other, e.g., non-laboratory, contexts (cf. Orquin & Holmqvist, 2018). In previous research by Taylor-Covill and Eves (2013, 2016; Eves et al., 2014), staircase slant was equally overestimated in a staircase image and in the presence of its real-world counterpart. To increase *ecological validity*, the 'realism' of, amongst others, experimental materials (Highhouse, 2009, p. 2), we took more than 500 real-world photographs from in and around Birmingham (UK). Our participants, students from the University of Birmingham, likely were residents in Birmingham, so we figured these staircases would resemble staircases participants encountered daily, staircases that are relevant for their locomotor behaviour. Using different real-world-outdoor scenes between stimulus categories, however, inevitably involves the danger of confounding image features that could systematically vary with the location of targets. Future studies should balance the use of specific scenes across participants. Pedestrians were excluded from all scenes, as they are known to attract attention (e.g., Birmingham et al., 2008; Foulsham et al., 2011;).

We measured response times, a main index of contextual cueing (Jiang & Sisk, 2019). Data were processed as suggested by Jiang and Sisk (2019) in excluding incorrect trials, accounting for positive skew, and using repeated measures analyses of variance. Participant responses were limited to a button press, reducing the potential for associating larger limb movements with responses (Jiang & Sisk, 2019).

In addition to the speed measures, in chapter three we present data on initial eye movements and on search duration measured in number of eye fixations. Consistent with what has previously been reported from eye tracking measurements in contextual cueing (Brockmole & Henderson, 2006a; Jiang & Sisk, 2019; Peterson & Kramer, 2001), fewer fixations were recorded in response to repeated, compared to novel, displays in our experiments, see supplemental material in chapter three. Eye tracking can be seen as a proximal measure for overt and covert attention allocation, since these forms of attentional shifts have been suggested to be functionally and spatially related (e.g., Deubel & Schneider, 1996; Godijn & Theeuwes, 2003; Henderson, 1992). Eye tracking allowed for a closer inspection of the time-course of contextually cued search, including the direction of initial saccades as well as overall search performance (cf. LoBue et al., 2014; Reynolds et al., 2009). Eye tracking also allowed for checking on potential eye-movement drift in-between stimulus presentations.

5.2.3 Sample size

Participant numbers of *N* = 120 (chapters two and three) and *N* = 40 (chapter four) in our experiments, were much higher than in previous contextual cueing research (e.g., Jiang & Sisk, 2019). Previous contextual cueing experiments compared learning in novel versus repeated, contextually cued, trial types (e.g., Chun & Jiang, 1998). Our main aim was to explore biased learning towards staircase location in real-world scenes. Since all our stimulus categories benefitted from contextual cueing, differential learning between categories was not as obvious as differential learning between novel and repeated scenes. Whilst learning was more rapid in the near, compared to the far, stimulus category in chapter two, the same numerical difference in learning slopes was not significant in chapter four, due to the smaller sample size, increasing confidence intervals by almost a factor of two. Similarly, a less fine-grained response measure, such as number of fixations compared to response latency, may also require a larger sample size to achieve equal precision. Our findings may be useful for future studies in enabling a more evidence-based choice of an adequate sample size depending on a study's aims and design.

5.2.4 Generalization of findings

The studies presented in this thesis were part of an exploratory investigation into biased search and learning of target locations relative to staircase location in the visual context. To increase comparability between studies, we used the same specific 18 repeated visual stimuli across all experiments, limiting generalizability, external validity, of our findings (cf. Orquin & Holmqvist, 2018). Future research will be able to determine the robustness of our results by utilizing a larger number of scenes from a variety of environmental contexts that include staircases (cf. Highhouse, 2009).

To increase the relevance of our staircase stimuli, pictures were always taken from a position of approaching the structure with the potential intention of climbing it (cf. research by Flykt et al., 2007; Hugdahl & Johnsen, 1989), comparable to the view previously associated with resources (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2016). This means, however, that we cannot differentiate biasing effects of staircases and potential biasing by a path about to be travelled (e.g., Foulsham et al., 2011). Future studies could compare effects of staircases an of other built environment that is, functionally, more closely related to staircases, such as a stone path or a bridge.

Furthermore, even though previous research suggested that perceptual biases are induced equally by 2-D and 3-D staircases (Eves et al., 2014; Taylor-Covill & Eves, 2013, 2016), more research is needed to explore the extent to which static visual images, viewed from a sitting laboratory position, have equal effects to static 3-D staircases with the immediate action opportunities they afford (cf. Foulsham et al., 2011; Proffitt, 2009; 't Hart et al., 2009). Another difference between our experimental situation and real-world encounters with staircases is the specific group of participants that were recruited for our studies: post- and undergraduate students from the University of Birmingham (UK), most of them associated with the School of Sport, Exercise, and Rehabilitation Sciences. Contrary to our predictions, resources were not related to performance (see section 5.1.4). It is possible that an overnight fast did not deplete resources enough to differentially affect performance of fasted and sated participants in this specific student example attending the School of Sport, Exercise, and Rehabilitation Sciences. Research on embodied perception suggested that biases in explicit overestimations of geographical slant were less pronounced in younger, lighter, and leaner individuals (Eves et al., 2014). We used means to describe trends and effects; i.e., as far as we know, reported effects are meaningful, only, to the average participant in our studies, a student at the School auf Sport, Exercise, and Rehabilitation Sciences.

5.3 Future directions

In this PhD thesis I investigated biased visual search in the presence of contextually novel, incidental scene content with staircases, as well as enhanced learning of target locations proximal to staircases. Reported biases in search and learning appeared to be spatially related to scene content that included staircase slant. Staircase slant precedes climbs of any magnitude throughout life.

Avoidance of climbs seems to be habitual, an automatic and rewarded behavioural response associated with the stable, recurrent contextual cue of a staircase (cf. Gardner et al., 2016; Lally & Gardner, 2013; Phillips & Gardner, 2016). In chapter three, I found that scene areas that included staircase slant attracted more than their fair share of initial saccades, especially when staircases had a greater number of steps; biases appeared to be based on quick, impulsive processing (Strack & Deutsch, 2004; Sullivan et al., 2015). Impulsive processes are fast and, often implicitly, inform cognition and action. Automatic, exogenous attention may have further increased visibility (Webb & Eves, 2005) and memorability (Eves & Puig-Ribera, 2019; Webb & Eves, 2007) of message banners attached to stair risers, compared to posters located a little distance from the stairs (e.g., Blamey et al., 1995; Kerr, Eves & Carroll, 2001a; Kerr, Eves & Carroll, 2001b; Webb & Eves, 2005). These interventions, aiming to promote stair climbing in the wider public, attributed their success to changes in contextual cues, i.e., colourful banners on stair risers, that can disrupt habits (e.g., Lally & Gardner, 2013; Wood et al., 2005) and to motivating intentional behaviour through written messages (e.g., Eves et al., 2012; Kerr, Eves, Carroll, 2001b; Lewis & Eves, 2012). Helping pedestrians to slow down prior to ascending stairs, or taking an elevator, may be a strategy that supports a more balanced activation of reflective and impulsive processing systems (cf. Sullivan et al., 2015); a message such as ‘take your time. Make a conscious decision. Enjoy your body. You are worth it.’ might be useful.

In chapter three, roughly 40% of first meaningful saccades were directed towards the specific quarter of the image that contained a staircase. As noted before, future studies could use paired (e.g., Fernández-Martin et al., 2017; Nummenmaa et al., 2009) or odd one out designs (e.g., Blanchette, 2006; Öhman et al., 2001) to formally compare attention towards staircases compared to other built environment. In the scope of a contextual cueing paradigm, future studies should balance specific scenes across participants to increase internal validity. More, responses to 3-D staircases could be formally studied, using head-mounted eye tracking devices. The sequence of a number of initial responses to the perception of staircase slant could be recorded in real-time, such as eye movements, feelings, and body movements, that were not accounted for in our studies but that may precede and explain behavioural avoidance of a climb. Future work could also tease apart effects of routes to be travelled and energetic costs involved in the same, e.g., by including images of ground-level paths and bridges. Other questions of interest may be: does visual attention orient to staircases in a certain distance and can effects of a visual potency of staircase slant be replicated in a 3-D environment, independent of resources?

In chapters two and four, learning was found to be more rapid and resistance to re-learning greater near staircases, compared to learning in staircase-free displays. A focus on local scene content around staircase slants could explain the heightened difficulty in orienting to new target locations farther from staircases (Zinchenko et al., 2020). Future research could compare the current findings to search biased by other potent stimuli, such as snakes, that could be included in the scene content. Overall, findings presented in this thesis were replicated across experiments based on specific scenes and target locations therein. Future research would ideally employ a wider variety of environmental scenes to test the generalizability of our findings.

5.4 Conclusion

This thesis was prepared in order to better understand responses to visual cues relevant for the habitual avoidance of staircase climbs. Chapter three reported an early search bias towards novel, incidental scene content with a staircase, related, in magnitude, to the costs associated with the potential climb. Chapters two and four provided evidence of enhanced learning and search of scene content near staircases, an effect independent of resources relevant for a staircase climb. Our findings are consistent with a developmental perspective where effort, previously experienced in climbs, is associated with the visuals of staircase slants, prepotent stimuli, that attract initial eye movements and stimulate learning, in order to efficiently prompt behaviour that minimizes energetic costs on a habitual basis (Proffitt, 2006). Habits, formed over a lifetime, may be difficult to reform, but previous success in public health interventions combined with our findings of biased and enhanced learning near staircases are promising. It may be that the observed biases can aid habitual avoidance learning *as well as* learning of novel behaviours, when relevant messages are affixed directly onto stair risers, where search and learning were biased across sessions. Additionally, the likely involvement of exogenous attention control points to a potential of the reflective processing system to support informed, healthy decisions in the face of the free healthcare afforded by staircases.

5.5 Literature

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