Interactivity in map learning: Does passive observation improve spatial recall?

by

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Abstract

The primary aim of this thesis is to identify the role of interactivity in map learning. Several definitions of interactivity exist such as those which emphasise control of movement, decision making, or rehearsal of spatial information (Chrastil & Warren, 2012; Nori, Grandicelli, & Giusberti, 2009; Vecchi & Cornoldi, 1999). In the present context, the phrase “interactivity” is used as a broad term for active and passive spatial learning. No prior studies have established whether activity or passive observation is beneficial to acquiring information from maps, highlighting the novelty of this line of research. Past work on interactivity with stimuli other than maps has sometimes suggested that active control is beneficial (Appleyard, 1970; Hahm et al., 2007). However, this finding has been inconsistent, with several studies showing no effect of interactivity (Foreman, Sandamas, & Newson, 2004; Wilson, 1999; Wilson, Foreman, Gillett, & Stanton, 1997) and others identifying a passive advantage (Experiments 2 & 3, Dodd & Shumborksi, 2009; Knight & Tlauka, 2017; Experiment 1, Wilson & Péruch, 2002). In the current research, the approach used to identify an explanation for the inconsistency in prior tests of interactivity relies on the working memory model (Baddeley & Hitch, 1974).

This thesis consists of six experiments, in which pairs of active and passive participants explored a map. The map was covered by a sheet of cardboard with a small hole in the centre. Active participants controlled exploration by moving the sheet of cardboard such that the central hole exposed different areas of the map. Yoked passive participants observed map exploration without communicating with the active participant. The map was explored either with or without a concurrent interference task. In Experiments 1-4, the modality of the interference task was altered between experiments to isolate the effect of loading different components of working memory (i.e., visuospatial sketchpad, phonological loop, central executive). Experiments 5 and 6 evaluated different map exploration methods to identify whether subjects were influenced by a goal-focused incentive. Goal-focussed exploration was intended to increase the ecological validity of the map learning task. In all experiments map recall was measured by a pointing task which required participants to imagine pointing toward locations on the map, and a drawing task in which participants sketched the explored map from memory.

The results for Experiment 1 demonstrated an interaction between visuospatial load and interactivity. Among subjects who conducted visuospatial interference during learning (i.e., high load), active learners were more likely to forget to include landmarks in their map drawings relative to passive subjects. In contrast, interactivity had no effect on landmark recall for subjects who explored the map without interference (i.e., low load). In addition, map learning was negatively affected by high visuospatial load. Experiments 2-4 replicated the detrimental effect of high load, such that high verbal (Experiments 2 and 3) and central executive (Experiment 4) demand impaired map recall. The results of Experiments 5 and 6 showed that the detrimental effect of high visuospatial load was retained when learners were given goal-focused instructions. The interaction between interactivity and cognitive load did not replicate in Experiments 2-6, and no experiments revealed a main effect of interactivity.

Taken together the results of Experiments 1-6 suggest that active map learning may demand greater cognitive resources than passive observation, however this does not result in a consistent disadvantage even under conditions of high task demand. It is therefore suggested that active advantages in spatial learning tasks are context dependent. The reliable dual-task interference effects provide evidence that map learning relies on

multimodal processing in working memory (i.e., visuospatial, verbal, and central executive), as opposed to being an exclusively visuospatial task.

Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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1. Structure of introduction

The introduction is structured in the following manner: The historical background of spatial memory research is discussed with reference to behaviourism and emerging cognitive psychology in the 20th century. It then continues with the discussion of a tripartite framework of spatial knowledge, which includes concepts of landmark, route and survey knowledge and their application in map learning. A discussion of map learning in general follows, identifying the influence of orientation specificity and spatial distortions. The concept of interactivity is then explored, as are the explanations for active and passive advantages in particular tasks. Based on the empirical evidence it is argued that the effects of interactivity in spatial learning have been inconsistent. It is proposed that the working memory model may provide an explanation for this inconsistency. This explanation is supported by a discussion of the modalities of information managed in working memory (i.e., visuospatial, verbal, central executive). Specifically, it is suggested that map learning relies on several components of working memory and that active and passive processes may be managed by discrete working memory components (Coluccia, 2005; Logie, 1995; Taillade et al., 2013; Vecchi & Cornoldi, 1999), potentially explaining inconsistencies in the literature. These arguments provide the rationale for the design of the experiments presented in this thesis, which evaluate the role of interactivity in map learning under different modalities of interference.

2. Spatial Memory: why is it important?

Spatial memory is critical to wayfinding, route planning, and orientation in unfamiliar environments. Given the ubiquity of scenarios that rely on spatial memory and the relevance of navigation in everyday life, it is important to examine the factors that affect spatial learning. From a theoretical point of view research on spatial learning improves our understanding of cognition and human perception (Montello, 2002). Moreover, spatial research increases our ability to design navigable cities and buildings as well as improve navigation aids (e.g., maps) and employ more effective navigation strategies. These factors highlight the relevance of the current research.

From an evolutionary perspective the importance of spatial memory is indicated by the fact that survival relies upon the accurate recollection of locations. For example, hunter-gatherer cultures relied on their memory of suitable foraging areas, clean water, and hostile territory (Gaulin & Fitzgerald, 1986). Without effective spatial memory early human's ability to survive would have been severely diminished. Likewise for non-human animals, survival is dependent upon spatial knowledge. Newly hatched birds cannot survive without a mother constantly returning to the nest with food. The mother bird relies on her spatial memory for appropriate hunting grounds as well as her ability to return to the same tree to feed her chicks. These processes are not without substantial difficulty as trees may appear visually similar or could be obscured by the landscape. Despite these challenges birds and other animals navigate with accuracy while returning home and travel great distances in migration (Wiltschko & Wiltschko, 1999).

The efficacy of spatial memory raises the question as to how animals, human and non-human, find their way without becoming lost or disorientated. Several theories have been proposed account for spatial memory. Early behaviourist theories (Hull, 1930, 1932) assumed that correct navigational decisions were positively reinforced whereas incorrect decisions received negative reinforcement. Positive reinforcement occurs if an action is immediately followed by a reward stimulus. For example, if an animal follows the smell of algae, this action may be rewarded by the discovery of a fresh water source. In contrast, negative reinforcement occurs if an action that results in a negative outcome is subsequently avoided. For instance, abstaining from eating a particular food which has made one sick in the past.

Behaviourist explanations suggest that spatial learning is largely a trial and error process, by which locating a goal destination (e.g., food, water, breeding grounds) rewards the preceding decisions, and motivates future decisions to be made in the same way. These behaviourist theories can be classified as stimulus-response explanations for spatial learning. Stimulus-response theories can be applied to contemporary human navigation, as we may avoid areas of cities with which we have had unpleasant experience (negative reinforcement), or frequently return to supermarkets that we believe offer the best value (positive reinforcement). However, the behaviourist explanation does not account for our experience that navigation is, at least in part, driven by a mental concept about the structure of our environment. Some areas of spatial learning depend upon an underlying cognitive structure, such as our concept of very large spaces (e.g., the shape of continents or cities). Very large spaces rely on abstract cognitive representations (Montello, 1993; Thorndyke & Hayes-Roth, 1982), which provide a sense of orientation independent of stimulus rewards.

Cognitive (mental) representations provide a basis for orientation when no previously reinforced cues are available. For instance, imagine the scenario in which a driver follows the same south-bound route to work every day. While making this journey, the driver discovers that her typical route is blocked by roadworks. To solve this issue, the driver could access a different south-bound route with the knowledge that she is headed in the correct general direction (south). Without a pre-existing mental representation of her city the driver may not be capable of reorienting in the correct direction (Lawton, 1996).

Furthermore, stimulus response associations pertaining to the typical route are not helpful in this situation because the learner must take a novel (i.e., not previously reinforced) route. The importance of cognitive representations in solving navigational problems highlights the need to investigate cognition in spatial learning.

Animal experiments provide clear examples of navigation and exploratory behaviour, which share broad application to human spatial learning. Tolman (1948) was one of the first to establish with experimental methods that non-human animals used mental representations (i.e., cognitive maps) which were independent of stimulus-response learning. This conclusion was driven by a series of rat maze experiments (references provided in Tolman, 1948: Blodget, 1929; Geir, Levin, & Tolman, 1941; Hudson, 1948; Krechevsky, 1932; Lashley, 1929; Shepard, 1933; Tolman & Honzik, 1930; Tolman, Ritchie, & Kalish, 1946). Hungry rats were placed at a fixed entry point and explored a maze with the goal of locating a food box. Exploration trials were generally repeated at twenty-four hour intervals. These trials demonstrated that the rats would locate food more quickly and make fewer errors (i.e., incorrect turns in the maze) with each consecutive attempt. The traditional behaviourist explanation stipulated that the rats received positive reinforcement for choosing turns and passages that led to the reward stimulus (i.e., food), whereas locations which did not lead to reward were avoided by negative reinforcement. Accordingly, it was inferred that discrete stimulus response pairings guided rats to the location of food with increasing efficiency. This explanation did not necessitate that the rats were accessing a mental concept of the surrounding environment.

The behaviourist account provided a parsimonious explanation for the rats' movement toward food, but missed the role of cognition. The potential importance of a cognitive explanation was implied by an experiment by Lashley (1929) in which a rat, which had previously explored a maze, broke out of the start box. The rat was able to move in a straight path over the top of the maze to the location of food and drop back into the maze. This anomaly suggested that the rat had developed a mental representation of the maze which was independent stimuli responses (i.e., discrete turns within the maze). The notion that rats could navigate towards a goal in the absence of discrete stimulus rewards motivated further research into rats' navigation to explain the limitations of the purely behaviourist explanation.

For example, Spence and Lippitt (1946) had rats that were neither hungry nor thirsty explore a simple 'Y' shaped maze (Figure 1). At the end of the left arm of the 'Y' food was found, whereas water was found at the end of the right arm. The rats were placed at the bottom leg of the 'Y' and were returned to a cage with other living rats as a reward for reaching the end of either arm of the 'Y', without having consumed food or water. This design ensured that the reward for choosing the left or right path was <u>not</u> related to the locations of food or water, since exploring either arm resulted in the same reward. In a subsequent trial, the same rats were deprived of either food or water. Hungry rats were more likely to travel directly to the left arm which had previously contained food, whereas thirsty rats were more likely to travel to the right arm which had previously contained water. These findings indicate a limitation of the purely behaviourist explanation. Specifically, the rats had learnt the location of food and water in the environment despite the fact that their previous reward (i.e., release from the isolated 'Y' cage) was independent of the locations of food or water (as rats were previously satiated). Spatial learning of food and water had therefore occurred in the absence of stimulus responses which targeted these specific goals. It follows that the rats had remembered the locations of food and water by devoting their location in the maze to a spatial representation, which was accessed when food or water became desirable.

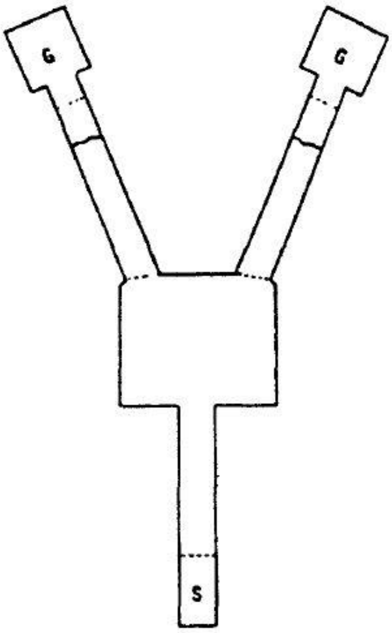

Figure 1. 'Y' Shaped maze explored by rats in Spence and Lippet (1946). The 'S' section denotes the start box area, while the 'G' sections denote the end boxes.

Tolman (1948) provided several other examples of rats using cognitive representations in wayfinding rather than pursuing stimulus rewards. For example, it was demonstrated that rats would explore novel routes in previously explored environments which were not consistent with efficiently obtaining a reward (Geïer, Levin, & Tolman, 1941). Second, rats were observed hesitating and glancing left and right before making exploratory decisions (Jackson, 1943). This behaviour showed that rats were not passively responding to a stimulus, but actively selecting features of the environment to home-in closer to their destination. Third, negative reinforcement of a visuospatial stimulus was shown to be supplemented by cognitive representations. This conclusion was inferred from an experiment in which rats would approach a food bowl, which could deliver an electric shock (unpublished Thesis by Hudson in Tolman, 1948). If a shock was delivered, rats would avoid the food bowl in future trials. However if the food bowl disappeared simultaneously while the shock was delivered (i.e., the lights would turn off), then rats would continue to approach the food bowl in future trials. In fact, after hidden shock trials rats would actively search for the source of their pain, despite the fact the location at which the shock was delivered (i.e., the food bowl) had been readily apparent. This finding implied an active search process *after* the stimulus event (i.e., the electric shock) to inform the rats' mental representations of danger rather than immediate stimulus response learning. Finally, it was shown that if a previously explored route to a destination was blocked, then rats would use a novel path which headed in the correct general direction towards the goal location (Tolman, Ritchie, & Kalish, 1946). This result suggested that rats could use a cognitive representation of the surrounding space to orientate toward their goal. These representations appeared to be available despite rats' previous experience of the maze consisting of stimulus rewards.

It could be argued that Tolman's work did not necessitate the presence of cognitive representations to explain these findings. This counterargument was explored by Thinus-Blanc (1996), who suggested that Tolman's (1948) paper presents a false dichotomy (see Thinus-Blanc, 1996, p. 8), in which stimulus responses and cognitive maps are the only possible explanation for spatial learning. Following Thinus-Blanc's argument, there may be alternative explanations for spatial learning which do not necessitate cognitive maps, or rely or stimulus responses. Nevertheless, Tolman's research certainly highlighted the deficiency of purely behaviourist explanations, and the consequent imperative to investigate cognitive mechanisms in spatial learning. These findings extended the scope of spatial memory research to include both behaviourist and cognitive models, which has influenced the current understanding of spatial knowledge in animals as well as humans. For example, the concepts of landmark, route and survey knowledge defined by Siegel and White (1975) assume the presence of an underlying cognitive system and have been widely used to explain how humans acquire spatial knowledge.

In the current dissertation, it is assumed that cognitive representations of space are a fundamental component of spatial memory. Given that the spatial information obtained from maps is useful in developing these representations (Moeser, 1988; Montello, 2002; Thorndyke & Hayes-Roth, 1982), the importance of researching maps is clear. It is possible that cognitive representations acquired from maps are affected by the manner in which information is obtained (Montello, 1993). The current investigation will examine whether there are differences in the quality of map learning achieved by active control and passive observation. This research addresses a significant gap in our understanding as interactivity has not been investigated in the context of map learning.

3. Spatial knowledge and human navigation

Map learning is particularly important because it aids navigation in unfamiliar environments and improves ones' representation of familiar environments (Montello, 2010; Thorndyke & Hayes-Roth, 1982). It is worthwhile to discuss the acquisition of spatial knowledge by navigation, and how maps can supplement this process. Navigation can be conceptualised in three stages (Ishikawa, Fujiwara, Imai, & Okabe, 2008). First one needs an accurate idea of one's position and orientation in the environment. Secondly, it is critical to have an understanding of the route between one's current location and destination. Finally, one needs to traverse the route successfully. Fulfilling these requirements is a simple task in familiar environments, but is prone to error and requires substantial cognitive effort in unfamiliar environments (Schmid, Richter & Peters, 2010). To understand how spatial memories are used in a wide range of navigation strategies, it is important to distinguish between different types of spatial knowledge. Siegel and White (1975) proposed a three-stage model comprising of landmark, route, and survey knowledge which defines the primary modalities of spatial information used in wayfinding.

3.1 Landmarks

Following Siegel and White's model, landmarks are defined as salient locations or objects which are remembered relative to the surrounding environment. Landmarks are critical navigation tools because they function as cues for further actions and as beacons that signify nearby destinations (Chrastil & Warren, 2013; Jansen-Osmann, 2002; Siegel & White, 1975; Werner, Krieg- Brückner, & Herrmann, 2000). Consider using landmarks as cues in an urban environment or busy city, where making the correct turn at an intersection from a number of choices is critical. In this scenario landmarks can serve as a position which cues other navigational instructions (e.g., "Follow the main road north until reaching the library, then head west"). By associating each landmark with a specific instruction the navigator exercises a type of memory mnemonic, which should improve recall. Landmark mnemonics split the demands of navigation into smaller sets of instructions, hence reducing cognitive load and improving wayfinding (Waller & Lippa, 2007). This method of spatial learning with landmarks is discussed in more detail in the discussion of route knowledge (section 3.2).

Alternatively, landmarks may serve as beacons which guide a subject to their destination, or the landmark may be the destination itself (Cornell, Heth, & Alberts, 1994; Thinus-Blanc, 1996; Waller & Lippa, 2007). Landmarks used as beacons do not cue a specific decision, but are used to aid orientation and ensure the correct heading (See Jansen-

Osmann & Fuchs, 2006). For example, a child might find their way home from school by walking toward the local bus stop, from which point he can view and move toward a nearby playground. The playground neighbours the child's home, which can now be reached directly. When used as beacons, landmarks provide a waypoint for progress through a landscape, allowing the learner to navigate simpler paths by homing towards salient landmarks. This strategy may be preferable in comparison to longer, more complex routes which rely on a series of instructions (O'Keefe & Nadel, 1978). When traversing mountainous terrain, for example, it may be easier to head toward a salient goal (e.g., a mountain peak) than remember a sequence of turns along a route.

Landmarks can therefore be used in two distinct navigation strategies (i.e., cues or beacons). Using landmarks as associative cues encourages the navigator to perform a cued recall task by pairing landmarks and decisions together as a set of items (Tlauka & Wilson, 1994; Waller & Lippa, 2007). To recall this information the learner is required to associate each landmark with the correct response (e.g., turn left, continue forward). In contrast, using landmarks as beacons requires recognition (rather than recall) as the learner distinguishes which landmark indicates the correct heading toward a destination. In the context of map learning landmarks can indicate points of interest, areas to avoid, or goal destinations (Ishikawa et al, 2008). A navigator could associate landmarks on a map with decisions or use landmarks as steps along a path. However they are used, landmarks are a critical element in map learning due to their role in providing points of orientation (Bosco, Longini, & Vecchi, 2004).

3.2 Routes

Spatial knowledge acquired during exploration is often framed by the route taken from a starting point to a destination. When navigating by following routes, our representation of space is largely derived from a series of decisions about how to reach a goal (i.e., route knowledge). Route learning is closely associated with landmarks, which often serve as interlinked nodes along a route. However at times landmarks may lack the required salience to serve as distinct nodes (Werner et al., 2000). When navigating indoors, for instance, salient landmarks may be scarce in comparison to those found in outdoor navigation (e.g., buildings, roads, large trees). If salient landmarks are unavailable, the learner will rely on alternative strategies (e.g., distal judgements) to cue decisions about when and where to turn (Jansen-Osmann, 2002). Navigation in hospitals provides an example of route knowledge in the absence of distinct landmarks as floors and hallways often appear visually similar (Moeser, 1988). Using landmarks as nodes is preferable because it attenuates load on working memory and leads to more efficient spatial learning (Jansen-Osmann, 2002).

Memory for routes is commonly acquired during repeated navigation (Meilinger, Frankenstein, & Bülthoff, 2013) as landmarks are joined together in a path such that the path itself becomes a unique spatial representation (Thorndyke & Hayes-Roth, 1982). For instance if a navigator walks the same route to the train station each morning he will initially rely on instructions about where to turn (e.g., turn left at the park, continue until the intersection, then turn right). Over repeated experience the entire route may be devoted to memory, and hence the learner will no longer be dependent upon specific instructions. Although he may notice landmarks along the journey to the train station, the route in its entirety may form a unique spatial memory independent of the contained landmarks. By developing knowledge of several interconnected routes, he may develop a more detailed and holistic representation of the environment known as survey knowledge (discussed in section 3.3).

Route knowledge obtained from navigation is associated with the distance travelled along the specific route rather than the straight-line distance between a start point and destination (i.e., Euclidian distance). Differences in concepts of distance were investigated in an experiment by Taylor, Naylor and Chechile (1999). Participants either navigated an unfamiliar building on foot or studied a map of the same environment. The on-foot navigation group demonstrated superior estimates of the total length of the route than the map learning group. However, the map learning group demonstrated more accurate Euclidian distance estimates than the navigation group (Thorndyke & Hayes-Roth, 1982). These findings suggest that on-foot navigation promotes spatial memory for a specific route rather than promoting a larger representation of the surrounding environment, whereas the opposite is true for an environment learned from a map.

Although maps are typically considered to rely on landmark and survey information (Thorndyke & Hayes-Roth, 1982), route knowledge may also play an important role in map learning (Bosco et al., 2004; Ishikawa et al., 2008). Bosco and colleagues (2004) investigated spatial knowledge acquisition in a map learning scenario. The authors were interested in sex differences in visuospatial ability, and the sex-associated strategies used in orientation tasks. Following a map learning exercise, participants were asked a battery of questions, which targeted landmark, route, and survey knowledge. Route questions emphasised an egocentric perspective and described routes with regards to instructions about which way to turn at certain points. For example, a route recognition question required that participants correctly identify the pathway between two landmarks from a set of three alternatives (only one of which was correct). The results showed that among participants with good orientation, men demonstrated superior route learning by comparison with women. This finding suggests that men may acquire route-centric information from maps more effectively than women. Importantly for the current context, the results of Bosco et al. imply that route knowledge may be an important component of the spatial information obtained from maps. It follows that evaluation of route knowledge may provide a sensitive measure of map learning.

3.3 Survey Knowledge

Survey knowledge describes large-scale mental representations of environments, often referred to as a “cognitive map” (Thinus-Blanc, 1996). Survey knowledge is map-like in the sense that the environment can be mentally represented from a top-down (i.e., “bird’s eye”) perspective where different interconnected zones or routes in the environment are represented with relatively accurate distances and space between them (Ishikawa & Montello, 2006). Euclidian information and allocentric spatial relationships are hence highly emphasised components of survey knowledge (Taylor et al., 1999; Thorndyke & Hayes-Roth, 1982). A unique feature of survey knowledge is the associated ability to make configurational inferences about spatial relationships in an environment, including presence of shortcuts or distance between visually disconnected locations. Such inferences are only available to those with survey knowledge because they rely on Euclidian information about the surrounding environment which is not supplied by knowledge of routes or landmarks alone (Chrastil & Warren, 2015; Meilinger, Frankenstein, & Bülthoff, 2013). For example, one could infer the presence of a shortcut by accessing survey knowledge and then by judging the optimal route between two locations (Rossano & Moak, 1988). Importantly, configurational inferences do not rely on personal experience with the shortcut itself. In contrast, knowledge for routes and landmarks is typically acquired experientially (Rossano & Moak, 1998; Thorndyke & Hayes-Roth, 1982, Moeser, 1988).

In the initial tripartite model of spatial knowledge proposed by Siegel and White (1975) it was theorised that survey learning was the final stage in a hierarchy of spatial knowledge acquisition. Upon initial exposure to an environment the learner was assumed to identify salient landmarks and use these as a primary navigation tool. The learner then sequentially associates landmarks in a path, resulting in route knowledge. According to the model, repeated and extensive route experiences provide the learner with the ability to integrate several routes into a single frame of reference. By gradually establishing knowledge of several interconnected routes, the learner then develops a cognitive map which enables configurational judgments. In accordance with this model, survey knowledge is built upon that of routes, which in turn requires a foundation of landmark knowledge.

It is noteworthy that the linear progression of spatial memory from landmark to survey knowledge has not received consistent empirical support. Survey knowledge can be acquired without extensive route learning, which in turn does not necessarily require landmark knowledge (Loomis et al., 1993; Moeser, 1988; Montello, 1988). Moeser (1988) compared survey knowledge acquisition of participants who studied a map of a hospital with long term employees of the hospital. The map learning group showed superior survey knowledge in several tests of survey knowledge relative to those who had prolonged experience inside the building. These results demonstrate survey knowledge acquisition in the absence of direct experience and suggest that maps provide an alternative source of survey knowledge.

Survey knowledge can also develop faster than Siegel and White's (1975) theory suggests, to the extent that cognitive maps may be acquired in parallel with landmark and route knowledge (Ishikawa & Montello, 2006). The speed of survey knowledge acquisition was demonstrated by Loomis et al. (1993), who found that blind participants could make spatial inferences about a route with which they had only limited tactile and proprioceptive experience, and no visual experience. This study demonstrates that survey knowledge can develop rapidly and does not rely on established landmark and route knowledge. A similar conclusion was reached by Ishikawa and Montello (2006), who had sighted participants travel in a car along a 2.2 kilometre route, repeating the same route over 10 weekly trials. The results showed that accurate configurational judgments were not dependent upon multiple trials, further suggesting that survey knowledge is obtained faster than Siegel and White's original model predicted. While the sequence of landmark, route and survey knowledge has not found consistent support, most components of the model are considered useful depictions of human spatial learning. Given widespread use of Siegel and White's model, the present dissertation uses concepts of landmark, route, and survey knowledge to aid discussion of map learning (Chrastil & Warren, 2012; Ishikawa & Montello, 2006)

Finally, it is worthwhile to qualify the term "cognitive map", which is often used in the context of survey knowledge. This phrase is somewhat misleading, as cognitive maps are not organised in the static format of a two-dimensional map (Thinus-Blanc, 1996). Like all memory processes, cognitive maps are dynamic, subjective, and prone to memory biases (see section 4.2). Furthermore, cognitive maps cannot be literally viewed from the bird's eye perspective available in real maps, as this perspective is typically reliant on inference rather than visual experience. Nevertheless, the term "cognitive map" provides a convenient means to describe survey knowledge which goes beyond simple routes in an environment. It should be understood that cognitive maps are not defined by the ability to imagine an environment from the top-down perspective, but from the configurational inferences enabled by survey knowledge.

4. Map learning

Survey knowledge is closely related to map learning as maps emphasise Euclidian information and an allocentric perspective (Zhang, Zherdeva & Ekstrom, 2014). Map learning enables rapid development of survey information by presenting large-scale environments in a visually accessible format (Farrell et al., 2003; Rossano & Moak, 1998, Thorndyke & Hayes-Roth, 1982). Unlike cognitive maps, real maps display landmarks and routes with a high degree of accuracy and preserve correct metric distances. Historically, the use of maps has enabled reliable navigation which could not have taken place otherwise (Montello, 1993). Likewise in the modern world, maps are often applied in handheld and car-mounted digital displays (Kelly, Carpenter, & Sjolund, 2015) as well as in traditional paper maps (e.g., road map books). Given the widespread use of maps, it is pertinent to research their role in human spatial learning, and the factors which may impact the quality of survey knowledge obtained from maps.

Past research has indicated that simpler maps facilitate more efficient survey knowledge acquisition than complex maps (Lloyd & Steinke, 1984; Schmid, et al., 2010; Wilkening & Frabrikant, 2011). Wilkening and Fabrikant (2011) investigated the effects of map complexity and time pressure in a map learning task which required the user to identify safe landing zones for a helicopter. Before studying the maps, participants indicated a subjective preference for maps which displayed higher realism and conveyed a greater amount of information (i.e., colour coded slopes, space represented in three dimensions). Despite preferences for complex maps, simpler two-dimensional maps enabled faster decisions. The authors suggested that simple maps conveyed important visual properties (i.e., safe landing zones) more clearly, and that the visual complexity of more realistic maps distracts the learner from critical information. It follows that visually attractive maps are not necessarily beneficial to spatial learning and that simpler maps may convey survey information more efficiently. Similar conclusions were reached in an article by Schmid et al. (2010), who contrasted maps which conveyed an entire environment with those which emphasised route-critical information. The authors concluded that simpler maps decrease visual clutter and enable more efficient way-finding, supporting the notion that two-dimensional plain view maps provide an effective source of survey knowledge in unfamiliar environments. Following this research, simple two-dimensional maps were used as experimental stimuli in the present experiments to provide optimal transfer of visuospatial information.

It is worthwhile discussing the classification of spatial knowledge obtained from maps because maps typically convey spatial information in an abstract format (Thorndyke & Hayes-Roth, 1982; Montello, 2002) and aid the rapid development of survey representations (Farrell et al., 2003; Zhang et al., 2014). The question is therefore raised as to why maps provide access to configurational information more quickly than other modes of spatial learning (e.g., route navigation). Following the work of Montello (1993), the acquisition of knowledge of very large spaces (e.g., the shape of continents, location of cities within a state) cannot be achieved by personal locomotion through the environment. Only abstract or symbolic representations of these spaces can reduce very large spatial relationships to a visually appreciable scale. Maps achieve this purpose by conveying a large amount of spatial material within “pictorial space”. Montello defined pictorial space as that of a small image which can be viewed without any locomotion by the subject.

As maps are viewed on a pictorial scale it follows that knowledge of large-scale environments acquired from maps is dependent upon accurate pictorial memory. Montello (1993) suggests that the study of small-scale pictorial images is consequently of great importance in map learning research. In contrast, the study of spatial information acquired through personal navigation does not have direct application in map learning. Montello’s argument points to the notion that research in map learning should evaluate subjects’ memory for the pictorial features of maps because this information is critical to the development of survey knowledge. The current dissertation addresses this concern by evaluating map learning with a drawing task (see section 9), which tested memory for the pictorial properties of a map.

Although Montello’s classification of maps as pictorial stimuli is important, it should also be acknowledged that maps are often used to aid locomotion (e.g., GPS used in cars). Spatial information obtained during locomotion is likely to differ from a strictly pictorial depiction of space, since the surrounding environment will influence spatial learning (Moeser, 1988; Thorndyke & Hayes-Roth, 1982). The classification of spatial representations acquired from maps may therefore differ depending on the map’s content and current application. In conclusion, two important points can be made following Montello’s (1993) discussion of the classification of knowledge acquired from maps. First, map learning is of critical importance to our understanding of humans’ perception of large scale space, yet these spaces are represented on a small pictorial scale. Second, evaluation of map learning should be tailored to measure the discrete classifications of spatial knowledge emphasised in the given task. In the study of pictorial scale maps it is important to measure subjects’ pictorial knowledge. Measuring pictorial representations can be achieved by asking subjects to reproduce studied maps in a similar pictorial scale (e.g., by drawing the map as accurately as possible).

4.1 Orientation Specificity

Although map learning provides the advantage of rapid survey learning, this comes at the cost of establishing an orientation specific representation of the environment (Arthur, Hancock, & Chrysler, 1997; Montello, 2010 Thorndyke & Hayes-Roth, 1982; Tlauka & Nairn, 2004). Maps are typically viewed from a static perspective, usually aligned with a coordinate system (e.g., cardinal directions) or salient egocentric preferences in the environment (e.g., with the navigator's initial view facing 'forward') (Evans & Pezdek, 1980; Tlauka & Nairn, 2004). Survey knowledge acquired from maps is therefore biased in the orientation in which the map is learned. For example, imagine studying a map of a university campus where "north" is aligned at the top of the map and the task is to navigate toward a building on the northwest corner of the campus. The navigator will likely orientate himself northward (the same orientation in which the map was learnt) before adjusting his heading 45° to his left and moving in a straight path to the destination.

This navigation strategy is effective, but causes problems if the navigator is required to make judgements from orientations that are not aligned with his initial view. Misaligned spatial judgements require mental rotation of mental representations, which increases cognitive load and is prone to cause errors (Evans & Pezdek, 1980; Levine, Jankovic, & Palij, 1982; Roskos-Ewoldson, McNamara, Shelton, & Carr, 1998; Sholl, 1987; Tlauka, 2006). The cost of misaligned spatial judgments was demonstrated by Roskos-Ewoldson et al. (1998), who had participants study route-centric or landmark-centric maps of small or large scale space. After studying the maps, participants completed a pointing task from their initial orientation and from misaligned orientations. The results showed greater pointing errors from misaligned orientations, with poor performance at 180° (i.e., contra-aligned) and the worst performance at 90° of misalignment (Experiment 2).

The finding that misalignments of 90° cause greater decrement than 180° has been replicated (Diwadkar & McNamara, 1997; Tlauka & Nairn, 2004), suggesting that the difficulty of misaligned judgments does not increase linearly from 0° to 180°. Recalling orientations which are contra-aligned (i.e., 180°) could be easier than orientations of 90° misalignment because the navigator needs only rotate their perspective to the opposite of their initial view (i.e., the "aligned" view). In this way, learners can reverse spatial information obtained from the initial orientation to make contra-aligned judgments. In contrast, recalling an orientation misaligned by 90° requires the navigator to rotate their cognitive map to a completely unfamiliar perspective. Unlike with contra-aligned judgments, misalignments of 90° cannot be imagined by simply reversing spatial information obtained from the initial learning perspective. As a result, greater cognitive effort may be required to imagine misaligned (e.g., 90°) compared to contra-aligned (i.e., 180°) orientations.

An alternative explanation is that participants adopt a specific strategy for contra-aligned judgments that does not require mental rotation. This proposition was put forward by Hintzman, O'Dell, and Arndt (1981), following a series of experiments in which participants were required to make pointing judgments from various degrees of misalignment. It was found that some participants would point with linearly decreasing accuracy from 0°-135° of misalignment, but accuracy would steeply improve at 180° (i.e., contra-aligned). It was proposed that these participants made contra-aligned judgments by pointing in the direction which would have been correct if they were facing the initial orientation (i.e., 0°), and then physically adjusting the pointing device to the opposite direction. This strategy improved contra-aligned judgments, and did not require rotation since participants used the initial orientation as a reference point. For those participants who did not identify this strategy and continued to use mental rotation, contra-aligned and misaligned judgments were made with a similar degree of inaccuracy. The fact that some participants discover a means to avoid mental rotation for 180° judgments provides a plausible explanation for the finding that contra-aligned recall is sometimes found to be more accurate than recall of 90° of misalignment.

In summary, research demonstrates that recalling maps from orientations other than that in which the map is learned detrimentally affects map recall. Contra-aligned orientations may be easier to recall than misalignments of 90°. However, this finding could be the result of strategic judgments of direction which avoid mental rotation. This discussion highlights the need to consider alignment effects in map learning as map recall is significantly affected by orientation.

4.2 Spatial Distortions

An important consideration in map research is the difference between a navigator's mental representation acquired from a map and the real space it represents. Due to the concise representation of space conveyed by maps, even minor distortions in encoding may negatively affect the accuracy a large portion of the environment. It is important to acknowledge the potential detriment of such spatial encoding distortions, as they highlight a potential drawback to the rapid survey learning enabled by maps. To encode maps effectively, a navigator will often use mental shortcuts (i.e., heuristics) to encode critical information (Coluccia, 2005). Heuristics aid specific navigation goals, but are used with the risk of distorting certain spatial relationships in the environment. For example, imagine navigating from an airport to a hotel in an unfamiliar city. One might focus on the route between the airport and the hotel and thus encode spatial information in this orientation. Aligning one's representation with this particular route may be helpful for navigating to the hotel, however such a biased orientation may be detrimental when making spatial judgments unrelated to the location of the airport.

A second heuristic related to map learning regards a bias to pay overly close attention to landmarks and turns, to ensure there is no deviation from an intended route (Bailenson, Shum, & Uttal, 1998, 2000). While orienteering, for example, one might view a map of the environment and determine that the optimal course follows a cliff face northward, only turning west once arriving at a lake, then continuing north etc. Although this strategy should ensure one does not get lost, it is possible that the acquired survey knowledge will be biased by the emphasis on locating particular landmarks (e.g., the cliff face), and executing correct turns (e.g., at the lake). Specifically, routes which are viewed on a map as containing a greater number of landmarks and turns are perceived as longer than those with fewer landmarks or turns (Bailenson et al., 1998; 2000; Sadalla & Magel, 1980; Seneviratne & Morrall, 1985). Focusing on these elements of a route could therefore exaggerate the distance travelled. In contrast, routes on a map viewed as containing very few landmarks or turns may be perceived as smaller, despite the fact that the absolute size of an environment is independent of these features. Researchers of map learning should therefore consider landmarks and turns in the design of map stimuli, to ensure their presence does not confound experimental manipulations. In the current thesis, participants' survey knowledge was evaluated with a pointing task in which participants would point toward particular landmarks from an imagined location on the map. It is possible that spatial distortions affected pointing accuracy in the current design. However, it was expected that such spatial distortions would equally affect active and passive participants because subjects shared the same view of the map regardless of their level of interactivity. Accordingly, spatial distortions were not expected to contribute to any effect of interactivity, the primary focus of this thesis.

5. Interactivity

Interactivity describes the degree to which a learner physically and mentally engages with navigation. In the context of map learning, specifically, interactivity refers to physical manipulation of maps (or map interfaces), and the decisions involved in how the map is used. Previous research in map learning has focused on how maps are processed in working memory (e.g., Coluccia, Bosco, & Brandimonte, 2007; Garden, Cornoldi, & Logie, 2002) as well as the acquisition of survey knowledge from maps compared to other modes of navigation (e.g., Thorndyke & Hayes-Roth, 1982; Zhang et al., 2014). These investigations have suggested that map learning is processed by the visuospatial sketchpad and that the information obtained from maps differs from that obtained by route navigation. Although informative, previous research has not addressed the question as to whether interactivity plays a crucial role in the acquisition of survey information from maps. Understanding the role of interactivity in map learning is the primary interest in the current thesis.

Past research has investigated interactivity in the fields of virtual reality (Attree, et al., 1996; von Stülpnagel & Steffens, 2013; Wilson et al., 1997) and real life navigation (Appleyard, 1970; von Stülpnagel & Steffens, 2012), but has not explored its role within a map learning paradigm. It is therefore unknown whether activity or passive observation is beneficial to map learning. The role of interactivity in map learning is worth investigating for two primary reasons. First, there is substantial inconsistency in the existing interactivity literature (Chrastil & Warren, 2012; Péruch & Wilson, 2004) as active control and passive observation do not appear to have a consistent effect on spatial learning (see section 5.1). It is possible that investigating interactivity in map learning will reveal a nuanced effect of interactivity which was not apparent when the construct was tested in other modalities of learning. As a result, researching interactivity in map learning could aid interpretations of findings in other fields of learning. Second, investigating interactivity in map learning has intrinsic value beyond understanding results in the existing literature. As discussed by Chrastil and Warren (2012), the underlying factors which affect map learning are still not well understood. Interactivity may be one such factor, as active or passive map learning may prove beneficial. It follows that increasing our understanding of interactivity in map learning will also improve our theoretical understanding of how we obtain spatial information from maps, and thus enhance our understanding of map learning.

The following paragraphs define active and passive spatial learning and discuss the current state of interactivity research, with regards to experiments from virtual reality, real navigation and visual recall (e.g., Appleyard, 1970; Chrastil & Warren, 2013; Henkel 2014; Wilson, 1999). The findings and implications of this research are linked to map learning wherever possible.

In general, active learners are characterised by making navigational decisions and physically controlling locomotion (e.g., walking, driving a car). In contrast, passive learners are those who observe the surrounding environment in the absence of control (e.g., a passenger in a bus). The specific definitions of what constitutes activity in particular contexts alters conclusions about differences between active and passive learning (Chrastil & Warren, 2013). Chrastil and Warren (2013), for example, define three crucial ways active learning has been characterised. First, active learners can be defined by podokinetic activity (i.e., motor & proprioceptive control), which describes the visuospatial information obtained by walking. Second, activity can be defined by vestibular activity, which described movement of the head and body rotations in a space. Third, activity is almost always characterised by decision making, which includes making judgments about which route is the most efficient or deciding how an environment should be explored. In the current research, activity is categorised by (1) physical control of map exploration and (2) making decisions about how to explore.

In interactivity research it is frequently argued that activity provides an advantage over passive observation (Appleyard, 1970; Chrastil & Warren, 2012; Péruch, Vercher, & Gauthier, 1995; Farrel et al., 2003; Wilson, 1999). The expectation for active advantage is driven by the notion that activity engenders greater engagement with learning than passive observation. Active engagement is assumed to reinforce spatial memory encoding and hence improve subsequent recall. More specifically, in active learners there is a direct correlation between a subject’s exploratory decisions and the accompanying movement and visual experience. The association of cognitive (i.e., decision making) and physical (i.e., control of movement) activity with visual experience may reinforce learning to greater extent than passive observation, in which such associations are not present. For example, when arriving at a hotel for the first time the learner is required to locate his room within the building. In the process, the learner must remember their room number, floor number, whether to turn left or right in the corridor etc. Locating the hotel room with this information constitutes active learning. The decisions and physical activity involved in locating the room may facilitate development of survey knowledge of the hotel. Alternatively, an example of a passive strategy would be if the learner simply followed an employee of the hotel to his room. In this case, the learner would not be required to engage with exploration by making decisions or physically exploring unfamiliar areas, which could lead to poorer survey knowledge acquisition.

Appleyard (1970) was the first to identify an active advantage in an applied study on survey knowledge. Participants from San Felix, Venezuela, were selected from matched demographics (e.g., similar socio-economic status and education levels) and asked to draw a map of their city and a separate map of their local area as accurately as possible. The clarity and accuracy of these maps was evaluated to determine which groups had access to more detailed survey knowledge of their environment. The important comparison for the present research was that between people who exclusively commuted by bus and people who exclusively drove cars for transport. Eighty percent of bus commuters were only able to produce simplistic route maps, which missed large areas and were not spatially accurate. In comparison, an education matched group of car drivers produced more accurate and detailed maps which depicted the environment without missing large areas.

These data were consistent with the notion that the active nature car driving provides a distinct advantage in the development of survey knowledge. This advantage was presumably caused by the necessity for car drivers to constantly update their position in the environment and consider optimal routes and navigational decisions along their journey. In contrast, passive bus commuters may rely primarily on route knowledge centred on their bus journeys, which does not facilitate development of survey information of the surrounding environment. These findings have motivated a substantial body of research on interactivity which has focused primarily on identifying the scenarios and mechanisms which enable an active spatial learning advantage (e.g., Foreman, Foreman, Cummings, & Owens, 1990; Hahm et al., 2007; Péruch et al., 1995; Wallet, Sauzéon, Larrue, & Kaoua, 2013; Wilson, 1999).

While informative, the data collected by Appleyard (1970) were correlational as the researchers were interested in measuring demographic differences in survey knowledge. As a result, the findings are subject to the generic weaknesses of correlational designs. It is hence possible that the relationship between transportation method and acquired survey knowledge was confounded by other factors. For instance, it is plausible that bus commuters' view of the environment was obscured (e.g., by other passengers or by the bus itself) to a greater extent than car drivers, who have a clear and wide view available. Bus commuters are also much more likely to attend to distraction in their journey (e.g., reading a book, talking with others) than car drivers, who are more likely to be focused on the road. These factors may result in a survey knowledge advantage in car drivers without reference to an interactivity explanation. Care should therefore be taken when interpreting the results of applied studies such as Appleyard (1970) as third variable explanations could drive differences between active and passive groups.

5.1 Inconsistent findings

The investigation of interactivity in controlled laboratory settings has yielded inconsistent findings (Attree et al., 1996; Wilson, 1999; Chrastil & Warren, 2012; Chrastil & Warren, 2013). Although some experiments have replicated a beneficial effect of activity (Péruch et al., 1995; Tan, Gergle, Scupelli, & Pausch, 2006; Farrel et al., 2003), other experiments have demonstrated a passive advantage (Sandamas & Foreman, 2014; Experiment 1, Wilson & Péruch, 2002) or no effect of interactivity (e.g., Foreman et al., 2004; Wilson, 1999; Wilson et al., 1997).

Mixed results were demonstrated in an experiment by Brook, Attree, Rose, Clifford, and Leadbetter (1999), who investigated interactive navigation in a virtual environment. Participants were instructed to learn the layout of a virtual environment and search for an umbrella which may or may not be present. Active participants controlled virtual navigation with a joystick, whereas passive participants observed a yoked recording of one of the active participant’s exploration sessions. Results showed that memory for the environmental layout was superior in active learners. However, memory for objects in the environment tended to be superior in passive learners (Experiment 1) or show no effect of interactivity (Experiment 2).

Brooks et al. (1999) interpreted these data to suggest a limited activity advantage, possibly caused by reinforcement of spatial memories by motoric control and a conception of moving the “self” through space rather than merely observing movement. This experiment provides an example of an active advantage in a controlled setting, but also shows that measures which display active advantages are often paired with those which show no difference between groups or trend toward a passive advantage. The latter findings should not be overlooked, as there may be a number of tasks which are unaffected by interactivity or to which passive observation is beneficial.

Equivalent or near equivalent spatial memory in active and passive learners has been demonstrated in a number of other experiments (e.g., Wilson et al., 1997; Wilson, 1999; Gaunet, Vidal, Kemeny, & Berthoz, 2001; Foreman et al., 2004). An example of similar performance in active-passive spatial learning was observed in an experiment by Wilson et al. (1997), who evaluated survey knowledge following exploration of a virtual environment. Importantly, activity was defined in this experiment by decision-making and physical control of exploration. These components of activity were isolated by having half the participants make decisions about how to navigate (active), while the other half did not make decisions (passive). Active and passive participants either explored the virtual environment by controlling a keyboard, or observed exploration by a yoked partner. This factorial design ensured that cognitive activity (i.e., decisions) and physical activity (i.e., keyboard control) were independently manipulated. Survey knowledge was measured by a pointing task and a map drawing task in which participants drew a two-dimensional map of the studied environment. Two experiments were conducted, the first of which focused on free exploration, whereas the second used a way-finding task to emphasise goal-driven navigation.

The results of both experiments demonstrated no advantage in survey knowledge following any combination of cognitive or physical activity. One interpretation of this data is that virtual environments differ in important ways from real environments, which obscures the active advantage. This is a valid concern. However, virtual environments are widely used in spatial learning research and the basic principles of navigation have been demonstrated to be present (Jansen-Osman, 2002), including the effects of interactivity (Péruch & Wilson, 2004).

The sensitivity of interactivity manipulations in virtual environments was investigated by Péruch and Wilson (2004). Participants were asked to explore a simulation of a university campus, after which survey orientation was measured in both the real university campus and in a simulation of the same campus. The results demonstrated an active advantage, which was consistent across both simulated and real testing scenarios. These findings suggested that virtual environments provide a valid means of investigating the role of interactivity in survey learning. Consequently, any differences between virtual and real environments do not appear to provide a sufficient explanation for the inconsistent results observed in the interactivity literature.

As pointed out by Wilson et al. (1997), a parsimonious explanation for the lack of interactivity effects in experimental settings is that passive participants pay particular attention to the task. In real life navigation it could be argued that activity provides an indirect advantage derived from visuospatial attention. This is because active learners have an incentive to attend to their surroundings (i.e., to avoid becoming lost) whereas passive observers do not. In laboratory studies, however, participants expect their spatial learning to be evaluated in a future test. As a result attention to visuospatial details may be unnaturally high in experimental scenarios. This demand effect may raise the performance of passive learners and attenuate the active advantage.

The attention explanation was investigated by Wilson (1999) to determine whether equivalence between active and passive learners could be attributed to high levels of attention in experimental subjects. Active participants used a keyboard to control movement through a virtual environment displayed on a computer monitor. Yoked passive participants observed exploration without communicating with the active participant. The environment consisted of six rooms, each containing four objects (e.g., a clock, bed, lamp, plant). All participants received instructions to search for particular groups of objects in the environment, which they were told would be the focus of a future memory test. Emphasising object search ensured that spatial learning of the surrounding environment was incidental and that participants' attention to survey information was low (for a similar procedure see Attree et al., 1996). It was predicted that using an incidental spatial learning procedure would reveal a beneficial effect of activity in survey knowledge. This hypothesis was based on the assumption that the requirement to control exploration would maintain attention to environmental details in active subjects. In contrast, the attention of passive subjects should have been focused on searching for objects, since navigating within the environment was not of concern.

Survey orientation was measured with a pointing task. Participants were placed in one of the virtual rooms and asked to adjust their view to point towards other rooms in the environment which were not visible from their location. Object recall was evaluated by asking participants to place objects in the correct spatial location on a two-dimensional map of the explored environment. Recognition of objects was evaluated with a picture identification task in which participants identified pictures found in the environment amongst an equal number of distractor objects. The results demonstrated equivalent survey knowledge and object memory in active and passive groups despite the incidental learning procedure. These data demonstrate that equivalent orientation of active and passive learners is unlikely to be the result of high attention in passive observers.

Taken together, the results of Wilson et al. (1997) and Wilson (1999) suggest that activity does not provide a reliable survey learning advantage over passive observation. More specifically, Wilson’s findings suggest that the equivalence of survey learning in interactivity research should not be attributed to high attention to the environment. The parity of active and passive subjects runs contrary to the traditional notion that activity provides a consistent benefit. In fact, it is implied that both activity and passive observation offer equally effective spatial learning in some scenarios (Chrastil & Warren, 2012) and that active advantages are not reliable across all tasks.

Another proposed explanation for the inconsistent findings in the interactivity literature is that several components of activity are not beneficial to spatial learning. This notion was explored by Chrastil & Warren (2013) who evaluated the acquisition of survey knowledge in active and passive learners in a virtual environment. Interactivity was manipulated between six groups of participants who experienced varied components of activity and passive observation. Participants searched for objects in a virtual hedge maze by walking, being pushed in a wheelchair, or viewing a video. These groups either determined their own path through the maze (active) or were guided through the maze (passive). By crossing groups this way, the authors were able to compare the contributions of decision-making (i.e., cognitive activity) with particular types of visuospatial information frequently linked with activity (e.g., control of body movements).

Specifically, the video group received only visual information whereas the wheelchair group received visual information and vestibular feedback associated with head movement. The walking group received visual, vestibular, and podokinetic (i.e., efferent motor commands and proprioceptive feedback) information associated with conducting body movements through space. Any differences in the quality of survey knowledge obtained between these groups were assumed to be the results of the types of information available in each group. For example, if the wheelchair and walking groups demonstrated superior performance then it would be concluded that vestibular information is a key component of active learning, since vestibular information was obtained by the wheelchair and walking groups (but not by the video viewing group). In contrast, if no differences were observed between groups then it would be concluded that visual information alone is the critical component of active learning, as all groups received visual information.

Various measures were used to evaluate survey knowledge including pointing and map drawing tasks. The results showed that decision-making provided no advantage to any group, and the critical comparisons were those between the different components of physical activity. The video and wheelchair groups demonstrated performance marginally above chance level, whereas the walking group showed superior survey orientation. These results suggested that decision making and vestibular feedback contribute little toward the potential benefit of activity. In contrast, active visuospatial information obtained by walking appears to be beneficial to survey knowledge acquisition. Extrapolation of these results could help us understand the inconsistency in interactivity literature. Specifically, experiments which focus on survey learning and rely on decision making or vestibular activity alone are not likely to detect an active advantage. More generally, these results reinforce the conclusion that activity should be understood as a dynamic construct, which has differential effects dependent upon which components are manipulated.

5.2 Potential passive advantage

It has also been observed that passive observation can be beneficial over activity (Wilson & Péruch, 2002; Experiment 1 Hahm et al., 2007; Dodd & Shumborski, 2009; Henkel, 2013). For example, Dodd and Shumborski conducted several experiments on visuospatial memory with object arrays. In Experiment 1, participants viewed a sequence of object arrays on a computer monitor. Each array presented either squares or circles for 1000ms (Figure 2). Physical activity was manipulated by having participants either point to the object array, or withhold the pointing response. Participants were required to point only to arrays of one type of shape (i.e., either squares or circles), and withhold their pointing response to the other type of object array. In the test phase, participants viewed one of the previously studied arrays and were required to indicate whether the location of objects matched or did not match the location of objects viewed in the learning phase. The proportion of correct responses was used as of measure of visual recall. Participants did not know whether the test array would contain squares or circles, and were hence required to attend equally to arrays of both shapes in the learning phase. This design replicated a previous experiment by Chum, Bekkering, Dodd, and Pratt (2007), who found that participants who actively pointed to objects demonstrated superior visuospatial memory for these objects compared to participants who withheld a response (i.e., passive viewing).

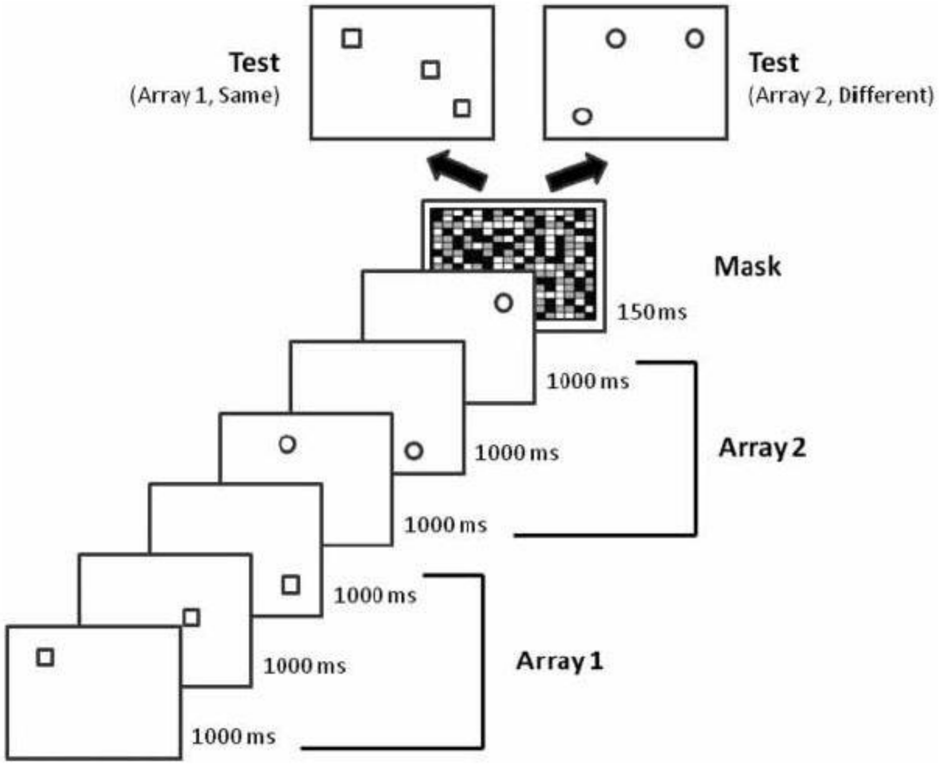

Figure 2. Object array sequence presented to participants in Dodd and Shumborski (2009). Six arrays (3 of squares, 3 of circles) were presented to participants, followed by a test array containing either squares or circles.

Experiment 1 replicated the results of Chum et al. (2007). Test arrays which were actively pointed to were remembered with greater accuracy than test arrays containing passively viewed objects. These findings suggested that coupling motor and visual activity by pointing to objects improved visuospatial memory for these arrays in comparison to passive viewing.

Dodd & Shumborski (2009) suggested that the active advantage in array recall might be caused by the inhibition of the pointing response in passive subjects. Recall that object arrays were viewed for only 1000ms, in which time participants attempted to visually memorise the array and execute the correct physical response (i.e., point or withhold pointing). It is possible that participants' default reaction was to point to objects, whereas withholding a response demanded additional conscious effort. The additional load required to inhibit the pointing response may have obstructed visual memory for passively viewed object arrays. It follows that the active advantage observed in Experiment 1 could have been caused by the cognitive demand of withholding a response rather than a benefit of active processing.

Experiment 2 investigated this possibility by replicating the previous design with the following differences. Object arrays presented in the learning phase contained only one type of object. As in Experiment 1, participants were instructed to point to either squares or circles, and withhold their reaction to the other type of object. Two different array sequences were presented, each of which contained either squares or circles, exclusively. As each array contained only one type of object, participants either pointed to all objects in the sequence or withheld the pointing response to all objects. This design ensured equal cognitive processing demands for objects which were pointed-to or passively viewed, as all objects within a sequence received the same response. Since all responses in a sequence were the same, passive viewing of objects was no longer confounded by inhibition of a pointing response in Experiment 2. This design diverged from Experiment 1, in which sequences contained arrays of both squares and circles, and hence required participants to execute or inhibit pointing responses discretely for each array.

The results for Experiment 2 demonstrated a passive advantage, as pointed-to objects were remembered less accurately than those which were passively viewed. These results support the notion that participants' memory for passively viewed objects in

Experiment 1 was detrimentally affected by inhibition of the pointing response. Furthermore, the results suggest that passively viewing objects may be beneficial to visual recall, provided the cognitive load associated with activity and passive observation is equal. A third experiment reduced cognitive load in both conditions by increasing the study time for object arrays in the learning phase to 2000ms rather than 1000ms, as was the case in Experiments 1 and 2. The passive advantage was maintained in Experiment 3, further suggesting that passive observation can provide improved memory for visuospatial stimuli.

These results are important for several reasons. First, the contrary results between Experiment 1 and the following experiments illustrate the dynamic effects of interactivity such that small changes in methodology can change an active advantage to a passive advantage. These results should not be interpreted as demonstrating that activity provides no benefit to visuospatial memory, but that advantages may be dependent on the context in which information is acquired. Second, the results of Dodd and Shumborski (2009) and others (Chrastil & Warren, 2012; Experiment 1 Hahm et al., 2007; Henkel, 2013; Wilson & Péruch, 2002) show that passive observation may also provide a context-sensitive advantage. Considering the results together it appears that the traditional concept of activity providing a benefit over passive observation may not apply to all learning situations. In fact, it is possible that specific tasks may benefit from an active or passive approach depending on the unique demands at hand. Further research is needed to determine the mechanisms responsible for active and passive advantages, which the current dissertation aims to address in the field of map learning.

Given that the results of interactivity research have been inconsistent (Chrastil & Warren, 2012; Sandamas & Foreman, 2007), it may be worth revising the hypothesis that activity provides a reliable advantage in visuospatial tasks. It may be more advisable to consider the demands of learning on a task-by-task basis, as certain scenarios may benefit from a passive approach. For example, previous empirical work in the domain of small scale visuospatial stimuli (e.g., museum displays, object arrays) has shown a passive advantage (Dodd & Shumborski, 2009; Henkel, 2014). Henkel (2014) conducted an experiment on memory for photographed objects. Participants were taken on a tour through an art museum and asked to take photos of particular objects while passively viewing other objects without taking a photo. The goal was to investigate whether photographing objects would result in improved or impaired memory for these objects. The researchers do not discuss interactivity specifically, as the emphasis is on the effects of photography on visual memory. However, the constructs of activity and passive observation are clearly present, as manipulating a camera to take photos requires a greater magnitude of physical and cognitive activity than simply observing objects. Consequently, the photo-taking condition can be considered physically and mentally active in contrast to the passive observation (i.e., no photo) condition.

Visual spatial memory for objects was tested the day after the learning phase took place. The results showed a photo-taking impairment effect, as more detailed visual descriptions of objects were made for passively viewed than for photographed objects. The spatial locations of passively viewed objects were also more accurately recalled compared to those which were photographed. This finding suggests that manipulating a camera to take photos obstructs encoding of visual and spatial details compared to passive viewing, possibly due to the greater cognitive load required to manipulate the camera. These results provide further evidence of a context-sensitive passive advantage.

Importantly, Henkel's (2014) original interpretation of the data focused on why photography results in participants dismissing objects from memory rather than highlighting any interactivity effect. It is also noteworthy that memory for small scale stimuli, including small objects, may be directly applicable to map learning. This assumption follows the argument from Montello (1993) that maps are pictorial (i.e., small scale) displays and are sensitive to the same manipulations as other small scale information. Given that Henkel showed that activity impaired visual memory for small scale objects, it stands to reason that activity could also impair visual memory for pictorial details on a map. It is therefore possible that the passive advantage in object memory may apply in the map learning domain.

6. Cognitive load

Throughout the present discussion of interactivity emphasis has been given to the potential role of cognitive load. The passive advantages observed in several discussed studies (i.e., Dodd & Shumborski, 2009; Henkel, 2014; Sandamas & Foreman, 2014) hinge on the assumption that high cognitive demands impair active learners. If cognitive demands are high, it follows that the mental load available for participants to perform other simultaneous tasks is limited (Baddeley, 2002). Furthermore, any simultaneous task demands are likely to impair performance, since demanding tasks require the majority of mental resources available (Baddeley & Hitch, 1974). Activity involves completing several tasks simultaneously (e.g., making decisions, controlling a joystick), whereas passive observation only necessitates a single task (i.e., visual attention) (Chrastil & Warren, 2012; Sandamas & Foreman, 2014). As a result of performing fewer simultaneous tasks passive observers may have greater cognitive resources available to devote to spatial learning in demanding tasks by comparison with active learners. The greater availability of cognitive resources may improve spatial learning in passive observers compared to active learners if task demands are high.

The benefit of passive observation in demanding visuospatial tasks has been discussed previously in the current thesis (see p. 39, pp. 43-44). For example, in Dodd and Shumborski (2009), recall of passively viewed objects was initially lower than pointed-to objects due to the additional demand required to inhibit a pointing response. However, Experiment 2 showed that passive viewing was beneficial if cognitive demand was controlled. Likewise, in two other experiments (i.e., Henkel, 2014; Sandamas & Foreman, 2014), activity appeared to be detrimental due to the additional cognitive load required to manipulate a particular device (i.e., a camera or keyboard, respectively). In the present dissertation, it is suggested that cognitive load may play a critical role in determining the context in which activity or passive observation is beneficial (Rudkin, Pearson & Logie, 2007; Sandamas & Foreman, 2014; Sandamas, Foreman & Coulson, 2009). Specifically, it is suggested that passive learning may be beneficial if cognitive load is high.

According to models of working memory high cognitive load obstructs learning, with encoding breaking down when mental resources cannot cope with simultaneous demand (Baddeley, 2002; Baddeley & Hitch, 1974; Rossano & Moak, 1998). Activity likely demands greater working memory resources than passive observation, as active learners must cope with a greater number of simultaneous tasks. For example, consider the scenario of a car driver and passenger attempting to navigate unfamiliar streets. The driver must contend with manipulating the steering wheel and pedals while also monitoring traffic conditions and adjusting the car appropriately. In contrast the passive passenger is only responsible for observing the surrounding environment. In this scenario, the cognitive load of the passenger is presumably lower than that of the driver. It is possible that complex navigational decisions would be processed more effectively by the passenger, who has greater working memory resources available than the driver. Scenarios such as these highlight the importance of investigating whether activity or passive observation is beneficial in a given scenario, as activity may not advantageous if cognitive resources are in high demand.

The cognitive demand of activity and passive observation in spatial learning has received some attention, though not in the field of map learning. For example, several virtual environment studies have examined the role of cognitive load in active and passive learning (Sandamas & Foreman, 2014; Sandamas et al., 2009; von Stülpnagel & Steffens, 2013). Sandamas and Foreman (2007) focused on interactive learning in children aged 5-8. An active group used a joystick to explore while a yoked passive group observed an adjacent monitor which displayed the view controlled by the active participant. The participants explored a virtual environment containing eight buildings which were distributed within a 2×2 grid of streets. Spatial learning was measured by asking the children to reconstruct the virtual environment with cardboard models in a similar 2×2 grid marked on the floor in real life. Passive children demonstrated superior environment reconstruction. One explanation for this finding is that actively controlling exploration with a joystick was cognitively demanding, while passive observation was not. A subsequent experiment (Sandamas et al., 2009) tested this hypothesis by replicating the experimental design in Sandamas and Foreman (2007). However, active children were given 5 minutes of training with the joystick before exploration of the virtual environment commenced. Training was expected to make children more familiar with their control interface (i.e., the joystick) and hence reduce active cognitive demand in the learning phase. Following training active participants showed superior environment reconstruction, suggesting that increasing interface familiarity can restore active advantage in virtual navigation tasks. These findings support the notion that cognitive demands can influence differences between active and passive groups.

More specifically, these studies (i.e., Sandamas & Foreman, 2007; Sandamas et al., 2009) suggest that activity can be cognitively demanding due to the greater number of simultaneous tasks incurred by comparison with passive observation. Sandamas and Foreman (2014) tested this explanation in a subsequent virtual environment experiment with adult participants. Active participants explored the virtual environment by manipulating a keyboard. Passive participants viewed a recording of exploration, either without interference or while simultaneously performing a concurrent task. The concurrent tasks were either simple (e.g., picking up and flipping a card) or complex (e.g., picking up cards and sequentially placing them in four locations in a clockwise order). The complex task was intended to impose additional cognitive load, similar to that of manipulating an unfamiliar input device. A test of participants' memory for virtual object locations provided a measure of spatial learning. The results showed that the passive group (without interference) demonstrated numerically superior object memory in comparison to all other groups (though not statistically different from active learners). In addition, the passive groups who performed simultaneous simple or complex interference tasks performed at least as poorly as the active group.

These data are consistent with the notion that activity is cognitively demanding relative to passive observation, as active subjects tended to show reduced object memory relative to passive observers. Importantly, passive subjects who performed interference tasks demonstrated impaired memory similar to that of active subjects. It is implied that active control imposes simultaneous task demands similar to performing a complex interference task. The authors interpret the findings to show that activity is generally advantageous, unless active control requires manipulation of an unfamiliar input device (in this case a keyboard). An alternative interpretation is that activity is intrinsically more demanding than passive observation as passive learners are not required to split cognitive resources between controlling exploration and learning their environment. It follows that passive observation may provide an advantage in complex tasks because passive observers have more cognitive resources available. A further implication of Sandamas and Foreman's (2014) results is that activity is only beneficial if decision making reinforces learning to a greater extent than passive observation, and if controlling exploration is relatively simple.

Following the work of Sandamas and Foreman (2007, 2014) and Sandamas et al., (2009) and others (Booth, Fisher, Page, Ware, & Widen, 2000; Chrastil & Warren, 2012; Dodd & Shumborski, 2009; Gardony, Bruyné, Mahoney, & Taylor, 2013; Henkel, 2013) the present thesis assumes that activity consumes greater resources in working memory than passive observation. The question of the potentially differential effect of interactivity (active versus passive) will be studied in the context of map learning. It is noteworthy that previous research on interactivity has not investigated whether manipulating the cognitive load of the primary learning task influences any difference in performance between active and passive map learners. Although the present work focuses on map learning, the acquired results may also aid interpretation of interactivity findings in other fields. The results may generalise to other fields because the varied cognitive demand of primary learning tasks may be expected to drive differences in the effect of interactivity, in general.

To reiterate the primary hypothesis, it is expected that experiments which use complex experimental tasks may demand greater cognitive load than simpler experimental tasks (Booth et al., 2000; Chrastil & Warren, 2012; Dodd & Shumborski, 2009; Gardony et al., 2013; Henkel, 2013; Sandamas & Foreman, 2007, 2014; Sandamas et al., 2009). It is hence possible that complex tasks are processed more effectively by passive observers as they have greater cognitive resources available. In contrast, simpler tasks may be managed equally well regardless of the learner's level of interactivity as both passive and active learners are able to cope with low demand. Evaluating this hypothesis should make some headway in explaining the inconsistent findings in interactivity research, as one should expect different patterns of interactivity results depending on the difficulty of the task at hand.

7. Working memory

The notion that the cognitive demands moderate the effect of interactivity is derived from working memory theory (Figure 3). It is therefore pertinent to discuss the role of working memory in map learning. Working memory theory is particularly important to consider in the present context because different modalities of information are processed by discrete components in working memory (i.e., the visuospatial sketchpad, the phonological loop, and the central executive) (Baddeley, Thompson, & Buchanan, 1975). Raising load on these components may have dissociable effects on map learning (Coluccia et al., 2007; Garden et al., 2002). It is therefore possible that high load may have a different effect on interactivity, depending on the modality of load imposed.

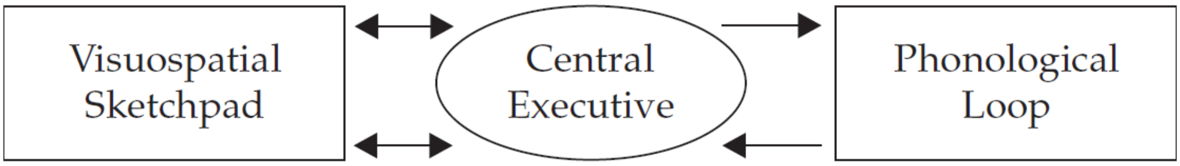

Figure 3. Original working memory model proposed by Baddeley & Hitch (1974).

7.1 Dual task design

Investigations of working memory and cognitive load commonly use dual task designs in which a subject completes a primary and secondary task simultaneously. If the two tasks compete for the same cognitive resource, then working memory demand is increased. Dual task designs assume that the components of working memory are limited in their capacity to process information. Simultaneous demands which exceed the capacity of a given component will detrimentally affect memory performance (leading to cognitive overload) (Allen & Willenborg, 1998; Baddeley, Lewis, Eldridge, & Thompson, 1984). Dual task designs have been used to determine the way in which tasks load on the components of working memory. For example, Baddeley and Andrade (2000) asked participants to consciously rehearse a visual image while performing a spatial tapping task, a verbal counting task or without interference. The results showed that spatial tapping reduced the vividness of memory for visual images, whereas verbal counting did not impact performance. The decrement in performance indicated that both spatial tapping and retaining visual images compete for the same cognitive resource (i.e., the visuopatial sketchpad).

In the same experiment Baddeley and Andrade (2000) investigated auditory memory for musical notes. This task showed the converse pattern of interference relative to that of visual images. Verbal counting reduced the vividness of participants’ memory for musical notes, whereas spatial tapping did not. These findings suggest that auditory memory for musical notes and verbal counting compete for processing capacity in the phonological loop. Dissociative interference highlights the strength of dual task designs as they enable conclusions regarding the modality of specific tasks in working memory. For example, if performance is negatively affected by visual or spatial interference, but not verbal interference, then the researcher may conclude the task loads on the visuospatial sketchpad.

Numerous studies have used dual task designs (or tasks derived from dual task designs, see Nori, et al., 2009) to demonstrate that spatial learning utilises the visuospatial sketchpad (Baddeley, 2002; Coluccia et al., 2007; Garden et al., 2002; Wen, Ishikawa & Sato, 2011). However, dual task experiments focusing on the contribution of the phonological loop in spatial tasks have generated mixed findings, with some work demonstrating a contribution for verbal memory (e.g., Picucci, Gyselinck, Piolino, Nicolas, & Bosco, 2013; Wen et al., 2011) and others showing no contribution or a limited contribution (e.g., Coluccia et al., 2007; Garden et al., 2002). The role of the central executive in spatial learning has received less attention, but research suggests it plays an important role in sequentially presented spatial tasks (Rudkin, et al., 2007).

Given that the present thesis aims to elucidate the role of cognitive load in interactivity the question arises as to whether the modality of the information is also important to consider. It might be possible, for instance, that raising load on the visuospatial sketchpad moderates the effect of interactivity in a different way to raising load on the phonological loop. Previous work has investigated the role of visuospatial memory in map learning (Coluccia et al., 2007; Garden et al., 2002). However, interactivity was not manipulated in these experiments and as such the effects of interactivity following different modalities of interference are unknown. The present research fills this gap in our understanding by testing the effect of raising load on the discrete components of working memory in a map learning task, while also manipulating interactivity. The following sections provide a summary of each of the components, and discuss how each contributes to spatial memory and map learning specifically.

7.2 Visuospatial sketchpad

The visuospatial sketchpad organises visual and spatial information including size, shape, speed, and location. Research has supported the notion that visuospatial abilities predict spatial learning performance (Fenner, Heathcote & Jerrams-Smith, 2000; Larrue, et al., 2014; Nori et al., 2009; Picucci et al., 2013). For example, Nori et al., (2009) measured participants' active and passive visuospatial skills before completing a way-finding task. Active skills included participants' ability to manipulate mental imagery and transform visual information (e.g., mental rotation) whereas passive skills demonstrated rote learning for spatial arrays or sequences (e.g., the Corsi block task). Participants with high active and passive visuospatial skills demonstrated faster and more accurate wayfinding in a navigation exercise than low visuospatial participants. The results of Nori et al. reinforce the connection between Baddeley's working memory model and spatial learning by demonstrating that visuospatial memory is closely tied to navigational ability. In addition, Nori's results suggest that both activity and passive observation are processed (at least in part) by the visuospatial sketchpad. This suggestion is derived from the finding that high active and passive skills predicted superior navigational performance. Given that navigation is highly reliant on visuospatial processing (Garden et al., 2002), it appears that active and passive learning are also reliant on visuospatial processing.

Some researchers advocate for a distinction between the visual and spatial components of the sketchpad. This idea is driven by dual task experiments which have dissociated the effects of visual and spatial interference (Baddeley & Lieberman, 1980; Pazzaglia & Cornoldi, 1999). For example, Baddeley and Lieberman asked participants to conduct simultaneous primary and secondary tasks, which were either visual or spatial. The visual interface task required participants to evaluate the relative brightness of a light. The spatial interference task involved blindfolded participants pointing toward a sound, the source of which moved around the room. Visual interference detrimentally affected performance in a visual memory test to a greater extent than in a spatial memory test. In contrast, the spatial interference task only negatively affected spatial (but not visual) memory performance. The dissociation of visual and spatial components is important to acknowledge from a theoretical perspective as it improves our understanding of working memory. However, most applied spatial learning tasks (e.g., on-foot navigation, driving) likely involve both components of the sketchpad (see Wen et al., 2011) such that interfering with either component could detrimentally affect performance. Map learning is no exception, as viewing and extrapolating information from maps likely involves both spatial and visual processing (Coluccia 2005; Coluccia et al., 2007).

The visuospatial nature of map learning has been demonstrated in experiments which specifically target the sketchpad (Coluccia et al., 2007; Garden et al., 2002;). Coluccia et al. (2007) investigated the role of the visuospatial sketchpad in map learning with a dual task paradigm. In Experiment 1, participants studied a map while simultaneously completing a visuospatial or verbal interference task, or in the absence of interference. Spatial tapping impaired map learning whereas verbal interference did not. These results support the notion that the visuospatial sketchpad is an important component in map learning and provide an example of dual task methodology used to establish the modality of a specific task.

7.3 Phonological loop

The phonological loop processes verbal information including speech production and speech reception (Baddeley et al., 1975). In contrast to the visuospatial sketchpad, the role of the phonological loop in spatial learning is not well established. Although verbal material is not intrinsically associated with spatial learning, research has demonstrated reliable verbal contributions in route knowledge acquisition (Picucci et al., 2013; Wen et al., 2011). For example, Wen et al. (2011) investigated the effects of spatial and verbal interference tasks during a route learning task. Participants watched five videos that simulated driving a car through downtown Tokyo while completing a lexical definition task (verbal), a clock imagination task (visual), a sound location task (spatial), or in the absence of interference. The authors found that participants with a high sense of direction remembered routes and specific landmarks less accurately following spatial and verbal interference. For low sense of direction participants, landmark recall was only negatively affected by verbal interference, and route knowledge tended to degrade following only visual interference. Picucci et al. (2013) also found a contribution of verbal memory in a virtual route-following exercise. Participants' development of mental representations were negatively affected by spatial and verbal interference tasks.

These findings demonstrate that the phonological loop may play an important role in route learning. Verbal resources may be involved in route learning due to the emphasis on sequential memory for a series of instructions (e.g., "turn left at the fire station, then right at the church"). Such instructions may be more easily rehearsed verbally, as opposed to remembering the spatial directions they represent. Route instructions are also often presented by voice or read from a display, which further encourages verbal retention of this information. It follows that the modality of route knowledge is not exclusively visuospatial, but is also tied to verbal – sequential information, and is therefore processed at least in part by the phonological loop.

In the field of map learning, previous investigations into the role of verbal information (Coluccia et al., 2007; Garden et al., 2002) have generated mixed results. Garden et al. (2002) found that articulatory suppression (i.e., verbal interference) impaired map learning, albeit to a lesser extent in comparison to a spatial tapping interference task. In contrast, Coluccia et al. (2007) found that map learning was impaired by spatial tapping, but unaffected by articulatory suppression. These findings diverge with regards to the role of the phonological loop in map learning, as Garden's et al. findings suggest a verbal contribution whereas Coluccia's et al. findings do not. It could be concluded that the phonological loop may contribute to map learning, but to a lesser extent than the visuospatial sketchpad. It is possible that the phonological loop is used in mental rehearsal of spatial relationships encoded from maps (e.g., "the fire station was a south-east of the bus stop"). However, on the whole participants may prefer visual rehearsal of map-based material (e.g., attempting to visualise the studied map) as this strategy matches the visual presentation format. Taken together, research in verbal interference suggests that the phonological loop may play a role in map learning. However, this requires further investigation. The present dissertation will address this inconsistency by investigating the role of the phonological loop in a map learning exercise (Experiments 2 and 3).

Chrastil and Warren (2012) argue that experiments on verbal memory in survey learning typically focus on spatial descriptions, which encourage sequential processing (see Kelly et al., 2015). Specifically, spatial descriptions order locations by reference to a previously established landmark (e.g., "The gym is one hundred metres north of the school"). This process evokes a verbal rehearsal strategy, which may explain the finding that verbal resources contribute to survey learning. In contrast to spatial descriptions, maps typically convey visual information simultaneously rather than sequentially, that is, the subject obtains spatial information about relative distance and location all at once without relying on any previous instructions. Simultaneous viewing may evoke a visuospatial rehearsal strategy rather than a verbal strategy (Coluccia et al., 2007), which might explain why traditional map learning is less likely to load on the phonological loop. The current map learning design emphasised sequential exploration, in which the map was gradually viewed. Given the role of verbal memory in sequential processing, it was expected that verbal interference would negatively affect map learning. It was not clear, however, whether high verbal load would moderate the effect of interactivity.

7.4 Central executive

The central executive controls attention, forward planning, and logic while also integrating information from the subcomponents into coherent memory representations (Baddeley, 1983; Baddeley, 2002; Gathercole, Pickering, Ambridge, & Wearing, 2004; Hitch & Baddeley, 1976). The role of the central executive in map learning has not received attention. The executive has, however, been investigated in the context of other spatial learning stimuli (e.g., Rudkin et al., 2007; Ang & Lee, 2008). Experiments focusing on other domains provide a basis from which expectations about the role of the central executive in map learning can be drawn.

Rudkin and colleagues (2007) investigated the contribution of the central executive in simultaneous and sequentially presented visuospatial tasks. In simultaneous tasks, participants could view and encode spatial properties all at once. For instance, in a Matrix pattern task participants were shown a series of different visual patterns in a matrix. Half the cells in each matrix were coloured blue. The objective was to identify on a subsequent test matrix which cells had been coloured blue on the previously studied matrix. Task difficulty was manipulated by incrementally increasing the number of blue cells in each matrix, and hence the number of locations to be remembered. Visuospatial ability was assessed by finding the point at which participants could no longer successfully recall the correct locations of blue cells. The matrix pattern task demonstrated simultaneous processing because the visuospatial information in each matrix pattern was immediately available. Specifically, the number and location of blue cells within each learned matrix was immediately apparent upon viewing the matrix as opposed to being acquired gradually over time.

Sequential tasks in Rudkin et al. (2007) emphasised the gradual acquisition of visuospatial information. For example, in a Corsi blocks task participants viewed 9 wooden cubes which were mounted on a wooden frame. The experimenter would point to two cubes in a predetermined order, after which the participant was asked to point to these cubes in this same sequence as the experimenter. Over repeated trials the number of cubes in each sequence was gradually increased. Memory span was assessed by recording the point at which participants could no longer reliably recall the correct sequence of squares. Corsi blocks demonstrated sequential processing because participants learned a single spatial sequence, which gradually increased in size. The task thus required maintaining attention over a period of time, in which participants' memory for the sequence gradually advanced in complexity. In contrast, in the matrix pattern task visuospatial information unique to each array was available all at once (i.e., simultaneous).

In three experiments, the authors found that executive interference diminished performance to a greater extent in sequential tasks (e.g., Corsi blocks) than in simultaneous task (e.g., Matrix patterns). These findings imply that the central executive is more critical in processing visual information that is gradually acquired (i.e., sequential) than when it is presented simultaneously. It is possible that the executive is critical in processing sequential information due to its function in integrating information and sustained attention, which may be of greater importance if visuospatial information is gradually obtained.

Specifically, sequential learning relies on the integration of new information with a pre-existing memory framework. By definition, this integration process takes place over an extended period of time and is thus fundamental in sequential tasks. By comparison, information which is simultaneously presented does not require integration to the same extent because visuospatial relationships are immediately apparent. Second, learning time is likely longer in sequential tasks compared to simultaneous tasks. As a result, sequential tasks require maintained attention and may therefore load the central executive to a greater extent than simultaneous tasks. Information from maps is typically acquired simultaneously (e.g., viewing a physical road map), but maps can also be viewed in a sequential format (e.g., scanning a large environment in google maps, GPS navigation). Rudkin's et al. (2007) findings imply that the central executive may play a greater role in map learning that emphasises sequential rather than simultaneous processing.

Ang and Lee (2008) investigated the role of the central executive in children's spatial learning. Children (aged 8-11) completed a Corsi block task, a mental rotation task and a spatial visualisation task while simultaneously performing a random number generation task or in the absence of interference. Random number generation requires executive resources (Towse & Neil, 1998) because participants are required to maintain attention to the numbers they produce to avoid repeating a previous or a linear sequence (e.g., 1, 2, 3). The random number generation task diminished performance on all three spatial measures, suggesting that the executive plays an important role in children's spatial reasoning. Although this experiment focused on children, it is reasonable to assume that the spatial reasoning children used to complete these tasks is similar to the processes utilised by adults. In map learning specifically, spatial attention and reasoning is required for the learner to translate two-dimensional images on a map to three dimensions in way-finding. Taken together these experiments (Rudkin et al., 2007; Ang & Lee, 2008) suggest that the executive may play a role in map learning, particularly if information is presented sequentially.

8. The current design

Given that the present investigation focuses on interactivity, it is worth discussing how this variable has been integrated into the working memory framework. Logie (1995) contended that the visuospatial sketchpad can be subdivided into distinct components. This model of visuospatial memory was developed by Vecchi and Cornoldi (1999), who dissociated active and passive components. The active component processes visuospatial material which requires cognitive manipulation and refreshes this information in working memory. Active tasks include those in which control of movement and responding appropriately to incoming spatial information is critical. For example, navigating a complex indoor environment (see Hölscher, Büchner, Brösamle, Meilinger, & Strube, 2007) constitutes an “active” task due to the demands on working memory. In contrast, the passive component of the sketchpad stores and retrieves visuospatial information from long term memory.

Vecchi and Cornoldi’s model of the sketchpad assumes that tasks lie on a continuum of interactivity such that active and passive components may be engaged to different degrees. It follows that visuospatial tasks may consume both active and passive resources to some extent. For example, driving a car is typically considered an “active” task (Appleyard, 1970). However traversing a familiar route may engage passive visuospatial memory because driving in this scenario is virtually automatic. Conversely, a passenger in a car would typically be considered “passive”. Nevertheless passengers may engage active visuospatial memory to cope with particular tasks. For example, a driving instructor in the passenger seat may utilise active visuospatial memory because she is required to make spatial judgments and evaluations, despite not being in physical control of the vehicle.

The separability of active and passive tasks in working memory is central to the current investigation, which stipulates that activity demands greater resource allocation than passive observation. Previous work is consistent with the assumption that active learning engages the visuospatial sketchpad to a greater extent than passive observation. (Chrastil & Warren, 2012; Sandamas & Foreman, 2014; Vecchi & Cornoldi, 1999). This notion is congruent with the assumed roles of the active processing (i.e., spatial manipulation, planning movement), which are likely to be more complex than those of the passive component (i.e., observation). Vecchi and Cornoldi (1999) suggest that the functions of the active component are also more reliant on input from the central executive, as active tasks require integration and maintenance of attention managed by the executive. In contrast, passive storage and retrieval does not require input from the executive. Dual input from the sketchpad and central executive may result in additional cognitive demand in active visuospatial tasks. Although Logie’s (1995) model of active and passive processing in working memory is consistent with the notion that activity is more demanding than passivity, empirical investigation is required to support this suggestion. Moreover, the role of working memory in activity and passive processing has not been investigated in map learning paradigm. The present thesis investigates the contribution of each component of working memory to active and passive learning in Experiments 1-4.

The greater cognitive demands associated with activity may impair visuospatial encoding if the demands of map learning are also high. Support for this notion was obtained in the results of a preliminary experiment (Knight & Tlauka, 2017). In this experiment, active and passive participants explored a map which was covered by a sheet of cardboard with a small hole in the centre. The experimenter manipulated the sheet of cardboard such that movements would cause the central hole to expose different areas of the map to participants. Active participants controlled exploration by verbalising movement commands (e.g., “north”, “south”, “east”, “west”), which prompted the experimenter to move the sheet of cardboard in the given direction. Passive participants observed map exploration without communicating with the active participant or the experimenter. Cognitive load was manipulated by the presence (i.e., high load) or absence (i.e., low load) of a spatial tapping interference task. The results demonstrated that map recall in active participants was impaired in the high load group whereas interactivity had no effect in the low load group.

This initial experiment (Knight & Tlauka, 2017) suggested that passive learners may be better equipped to cope with high load due to greater availability of cognitive resources. In addition, the results provided a foundation to investigate the moderating role of cognitive load on interactivity. Although the findings of Knight and Tlauka (2017) were consistent with the primary hypothesis of this thesis, several important questions remain unanswered. Specifically, will the active disadvantage under high load replicate? Is active disadvantage contingent upon high visuospatial load or can high load of any modality produce the same disadvantage? Does the high load active disadvantage generalise to different map learning tasks (i.e., free exploration vs. goal-driven maps)? The present dissertation aimed to answer these questions. Although the current findings pertain to map learning specifically, it is possible that the moderating role of cognitive load could aid our understanding of interactivity research in other domains (e.g., virtual reality, real life navigation). Consequently, a further motivation was to identify whether cognitive demands may provide an explanation for null findings (e.g., Foreman et al., 2004; Wilson, 1999) and passive advantages (e.g., Experiments 2 & 3, Dodd & Shumborksi, 2009; Henkel, 2014) in interactivity research.

To achieve these ends, the present thesis evaluated active and passive map learning under conditions of low and high simultaneous cognitive demand. A map learning procedure was employed, in which a map was covered by a sheet of cardboard with a hole in the centre. Active participants physically controlled how the map was explored by gradually viewing different areas though the central hole in the cardboard. Passive participants simply observed without communicating with the active participant. This design followed previous research on interactivity in other fields (Attree et al., 1996; Wilson, 1999), which used yoked active and passive groups. Yoked groups ensured that the visual information obtained by active and passive participants was identical.

To manipulate cognitive load, a dual task design was employed. Participants (both active and passive) explored the map while conducting a simultaneous interference task (high load) or in the absence of interference (low load). The modality of the interference task used to raise load varied between experiments. Experiment 1 used a spatial tapping task, targeting the visuospatial sketchpad in a similar fashion as Knight and Tlauka (2017). Experiments 2 and 3 investigated the phonological loop using verbal backwards counting and articulatory suppression interference tasks, respectively. Experiment 4 focused on central executive load, for which an *n*-back interference task was employed. Experiments 5 and 6 utilised the same spatial tapping task employed in Experiment 1, and hence targeted visuospatial memory. Importantly, the maps studied in Experiments 5 and 6 differed from those in the previous experiments as participants were required to evaluate salient paths during exploration.

It was expected that in the low load task, map recall would not differ between active and passive groups. In the high load task it was expected that only active learners would be negatively affected as passive participants presumably have the cognitive resources available to cope with increased demand. This hypothesis follows the rationale that activity demands greater visuospatial resources than passive observation (Logie, 1995; Sandamas & Foreman, 2014; Vecchi & Cornoldi, 1998). This research is important because active learners may be disadvantaged in experiments which use more difficult tasks. Conversely, it is possible that experiments which use simpler tasks may not be sensitive to manipulations of interactivity because both active and passive learners may be able to cope with low task demands.

The explanation above diverges from previous work which has attempted to explain the inconsistency in interactivity research (Chrastil & Warren, 2012; 2013; Wilson, 1999). For example, Chrastil and Warren attributed the inconsistency to differences in the way that activity was defined, whereas Sandamas et al. (2009) suggested that active subjects are disadvantaged due to the necessity to control unfamiliar interface devices (e.g., a joystick). Wilson (1999) suggested that attention to the environment may benefit passive observers and therefore attenuate the expected active advantage. These findings were valuable because they demonstrated that the effects of interactivity are contingent upon secondary factors which may differ between experiments. However, these results do not address the point raised in the present thesis, i.e., that activity may be less beneficial than is typically expected due to its inherent cognitive demand and the cognitive demands of the task at hand.

9. Pointing and drawing tasks

Pointing and drawing tasks were used to evaluate spatial memory in the current experiments. These tasks were chosen because they provide an informative assessment of survey knowledge and have been widely used in the previous literature (Blades, 1990; Lawton, 1996; Waller, Loomis, & Steck, 2003; Waller, Loomis, & Haun, 2004; Wilson, 1999; Zhang et al., 2014). Pointing tasks assess orientation from an egocentric perspective whereas map drawing tasks evaluate participants' allocentric (i.e., "bird's eye view") perspective (Wilson et al., 1997). Both measures are indicative of survey knowledge and are appropriate measures of map learning (see Coluccia, 2005; Coluccia et al., 2007; Ishikawa et al., 2008). The following paragraphs explain these tasks in more detail and highlight their application in the current design.

In pointing tasks (i.e., "judgement of relative direction" or "point to unseen target task") participants are asked to imagine standing at a particular location with a given heading and then instructed to point in the direction of a target. For example, "Imagine standing in your kitchen facing north, now point to your workplace". Pointing in the correct direction requires that the subject access a survey representation and orientate herself accordingly. Poor performance in pointing tasks is typically caused by inaccurate mental representations, which do not correctly portray the relative locations of landmarks contained in the pointing question (Zhang et al., 2014). Absolute angular errors are typically used to measure pointing accuracy (Donaldson, Tlauka, & Robertson, 2013; Lindberg & Gärling, 1982; Wilson, 1999). Absolute errors demonstrate the difference in degrees between the direction of the target and the direction indicated by the subject. Whether the subject overshoots their direction estimate to the left or right of the target is ignored by this measure, only the absolute angular deviation from the target is considered. Lower errors (closer to 0°) indicate accurate pointing judgments whereas higher errors (closer to 180°) indicate poor performance. Pointing errors of 90° demonstrate performance at chance level, as there is equal chance for participants to point anywhere between 0° (exactly towards the target) and 180° (in the opposite direction to the target). Pointing errors are used as an indication of survey knowledge because the participant is required to make configurational inferences regarding the relative locations of landmarks (Chrastil & Warren, 2013).

A wide body of research has demonstrated that pointing tasks are sensitive measures of orientation bias (e.g., Sholl, 1987; Waller et al., 2003; Tlauka, 2006; Ishikawa et al., 2008). Orientation effects are important to acknowledge in the context of map learning as environments are encoded in the orientation in which the map is learnt (Thorndyke & Hayes-Roth, 1982). For example, if a map is learned in a north facing orientation, then the learner's mental representation of the map will be biased to recall information in a northward perspective. Pointing judgments aligned with the original orientation (i.e., with north at the top) are consistent with the learners' mental representation (Frankenstein, Mohler, Bülthoff, & Meilinger, 2012). In contrast, pointing judgments made from misaligned (e.g., facing west) or contra-aligned (i.e., facing south) orientations are inconsistent with the original orientation (see section 4.1).

In the case of misalignment the learner is required to mentally rotate their perspective to a novel orientation. Mental rotation demands additional cognitive load (Jansen, Schmelter, Kasten, & Heil, 2011) and detrimentally affects pointing accuracy (Aretz, 1992; Montello, 2010; Sholl, 1987; Thorndyke & Hayes-Roth, 1982; Tlauka, 2006). In the current research, orientation effects were incorporated into the task by asking questions which were both aligned and contra-aligned with the learning orientation. It was expected that participants would encode the map in the learned orientation (i.e., with north at the "top") and demonstrate a typical alignment effect.

Drawing tasks have also been widely used to evaluate spatial learning (Gardony et al., 2013; Waller et al., 2004; Wallet et al., 2013; Zhang et al., 2014). In these tasks, participants sketch by hand a simple two-dimensional layout of a studied environment. It is emphasised that the landscape should be drawn to scale by retaining correct spatial relationships between landmarks. Map drawing can be evaluated by landmark placement, which describes the distance between where participants place landmarks on their drawing and where these landmarks should have been placed (Lawton, 1996). Relatively low landmark placement errors indicate metric survey knowledge that closely matches the studied environment. A benefit of drawing tasks is that they are consistent with Montello's (1993) classification of map learning as memory for small pictorial stimuli. Specifically, drawing tasks are pictorial in size and are generally similar in scale to the original map stimuli. Evaluating maps as pictorial stimuli is advantageous because this tests participants' memory for the small-scale visuospatial details presented on the map rather than testing abstract knowledge of the environment the map represents.

The combination of pointing and drawing tasks provided a comprehensive assessment of map learning. Pointing judgments demonstrated participants' egocentric orientation in the studied environment whereas the drawing task directly measured pictorial memory for the map. It was expected that pointing and drawing performance would be negatively affected by high load (i.e., simultaneous interference). An interaction was also predicted between interactivity and cognitive load. In the low load task no effect of interactivity was expected whereas active participants were expected to be negatively affected by high load to a greater extent than passive observers.

10. Experiment 1

The primary aim of Experiment 1 was to determine whether a spatial interference task (tapping) would cause the predicted interaction between interactivity and cognitive load. Spatial tapping is typically conducted on a small matrix within hands' reach of the participant (Smyth, Pearson, & Pendelton, 1988). The participant is instructed to physically touch cells in the matrix in a specific sequence and at a constant rate. This task requires that the subject retain a spatial sequence in working memory, execute physical movements, and visually confirm tapping accuracy. Given the clear visual and spatial demands of spatial tapping, the task is widely used to raise visuospatial load (Coluccia, 2005; Farmer, Berman, & Fletcher, 1986; Garden et al., 2002; Smyth et al, 1988). Map learning also demands visuospatial resources (Coluccia, 2005; Coluccia et al., 2007; Chrastil & Warren, 2012; Garden et al., 2002). Following the dual task rationale, the demands of spatial tapping were expected to overlap with those of map learning and raise load on the visuospatial sketchpad. It was expected that active learners would not cope with increased cognitive demand because they have fewer cognitive resources available by comparison with passive observers (Sandamas & Foreman, 2014). In contrast, when participants explored the map without interference no difference was expected between active and passive learners.

The design of the map learning task in Experiment 1 followed a previous experiment conducted by the current author (see Knight & Tlauka, 2017). Participants sat at a desk and viewed a map (Figure 4) which was covered by a sheet of cardboard with a small hole in the centre. Active participants gradually explored the map by moving the sheet of cardboard so that the central hole exposed new areas while passive participants observed. Spatial tapping was conducted with participants' feet because active participants' hands were busy controlling map exploration. After completing the map study phase, a pointing task and a drawing task were used to evaluate participants' spatial recall.

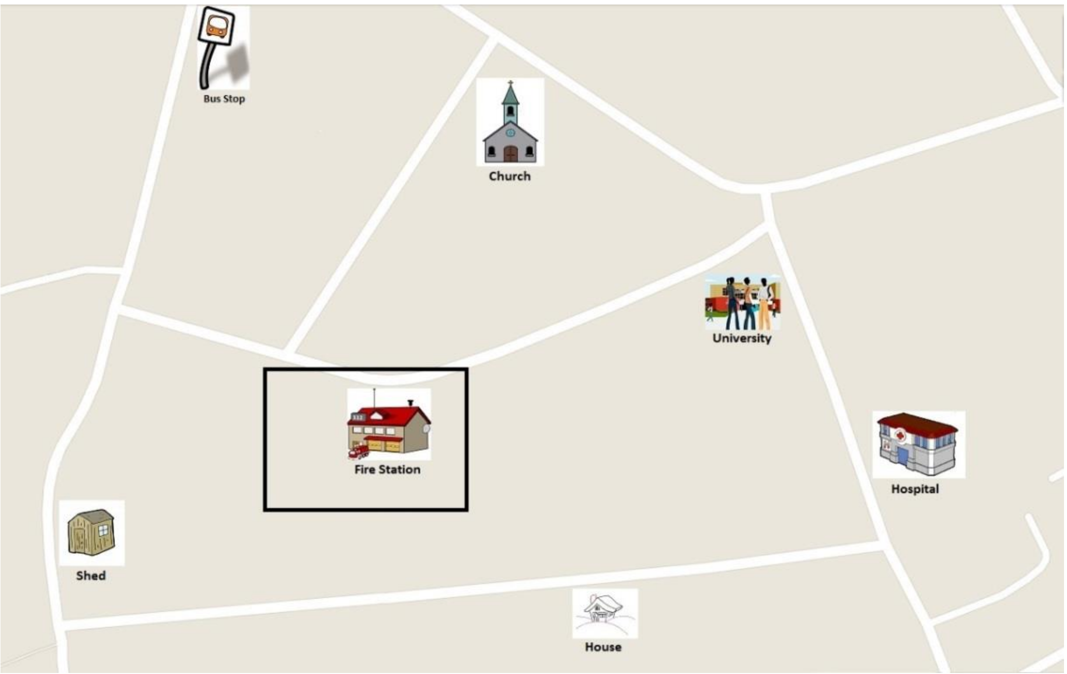

Figure 4. The map explored by participants during the study phase. Note that the map was placed under a sheet of cardboard with a 82×71mm hole in the centre (relative size illustrated by the black rectangle).

Method

Participants

Eighty university students (61 females, 19 males), aged 17-62 with a mean age of 24, took part. Participants received course credit or were paid $15.00.

Materials

An A3 sized map (297mm × 420mm) (Figure 4) was presented to the students. The map was covered by an A2 sized sheet of cardboard (621mm × 755mm) during the learning phase (Figure 5). The cardboard had a 82×71mm hole cut in the centre, which allowed participants to view approximately 5% of the map at a given moment in the study phase. The cardboard also indicated the directions ‘North’, ‘South’, ‘East’, and ‘West’. North was aligned with the top of the map. For the spatial tapping interference task a 2×2 grid on an A4 sized sheet of laminated paper (210mm × 297mm) was employed. The numbers 1-4 were printed in a clockwise sequence in ascending order in the four cells of the grid.

Figure 5. Sheet of cardboard manipulated by active participants to explore the map in the learning phase. Passive and active participants sat side by side such that both had the same view available.

A pointing device was used to assess participants’ knowledge of the map. The device consisted of a pointer mounted on a tripod (height: 1.40 metres, see Appendix A). The pointer could be rotated 360 degrees around the horizontal axis, providing a measure of response accuracy (in degrees). The time taken by participants to indicate the direction of an object was unobtrusively recorded using a hand-held digital stopwatch. Each direction estimate was timed from the moment the experimenter named the object to the response. For the map drawing task the students were given an A4 sized sheet of paper to complete a freehand sketch of the map.

Procedure

Four groups of participants, the factorial combination of activity type (active, passive) and cognitive load (spatial tapping, no tapping), were tested in the experiment. The experiment was conducted in two stages: a study phase and a testing phase.

Study Phase

Before initiating the experiment, participants read a letter of introduction which outlined the experimental procedure (Appendix D) and signed a letter of consent (Appendix E). Participants were asked to sit at a table with the map placed in front of them on the table. The map was covered by a sheet of cardboard with a small hole in its centre. Active participants were instructed to explore the map by moving the sheet of cardboard, thus making different parts of the map visible through the central hole in the cardboard. Passive participants were instructed to observe the areas exposed by the hole in the cardboard without communicating with the active participant. The sitting position of active and passive participants (left versus right side of the table) was counterbalanced. Participants were asked to attend to the spatial relationship between the landmarks.

Participants in the spatial tapping group performed the spatial tapping task concurrently while exploring the map. To facilitate foot tapping, an A4 sized 2x2 matrix was placed on the ground under the desk used during the study phase (see Appendix B). Participants used one foot to tap the numbers 1-4 in ascending order at the rate of one tap per second. The experimenter demonstrated the procedure to ensure understanding. It was emphasised that participants should focus their visual attention on the map while completing spatial tapping to their best ability. The experimenter observed participants for any significant deviation in spatial tapping accuracy or speed and corrected any deviations. For example, the experimenter would intervene if a participant skipped one cell in the tapping matrix in more than one consecutive sequence. Likewise, the experimenter would inform the participants if he or she was tapping noticeably slower or faster than the given rate of once per second. Participants had 2.5 minutes for map exploration (Thorndyke & Hayes-Roth, 1982).

Testing Phase

To initiate the testing phase, one participant was asked to leave the laboratory while the other participant completed the pointing task. Following the procedure of Wilson and Péruch (2002), the participant waiting outside was asked to rehearse the image of the map until their test began. The order of testing active and passive participants was counterbalanced. In the pointing task, participants made direction judgements to the landmarks. Subjects were asked to imagine standing at a landmark while pointing toward another landmark with the pointing device. For example, participants were asked “Imagine standing at the Fire Station facing north. Point to the University.” The pointing task consisted of sixteen questions, half of which were aligned with how the map was explored (facing north) and the other half were contra-aligned (facing south).

After completing the pointing task the participants were provided with an A4 sized sheet of drawing paper. Participants were asked to draw the map as accurately as possible by including the correct landmark locations and the spatial relationship between landmarks (for a similar procedure see Waller et al., 2003). For an example of participants’ map drawings, see Appendix C. The students could not see each other’s drawings during this part of the experiment. The students were also asked to draw a compass on their map to indicate its orientation and informed that the drawings should be completed within 1.5 minutes. The maps were rated for accuracy using three methods: subjective ratings, landmark placement errors and landmark recall. Subjective ratings were obtained from two independent raters who evaluated the maps on a 1-10 scale, with higher scores indicating greater accuracy. Placement errors were calculated by measuring the distance between where participants placed landmarks and the landmarks' true locations (Sandamas & Foreman, 2007). Landmark placement was measured by overlaying a scale acetate image of the correct map onto the drawn maps. Landmark recall was the number of landmarks participants forgot to include in their drawn maps.

Results

Independent samples t-tests were used on pointing errors and response latencies to evaluate whether there was any difference in performance between participants tested first or second in the pointing task. The results revealed that order did not significantly influence performance (all *p*s > .50).

Pointing Task

The results were analysed employing analyses of variance (ANOVAs) with activity type (active, passive) and cognitive load (low, high) as between-participants factors and alignment (aligned, contra-aligned) as a within-participants factor.

Analysis of absolute errors in the pointing task indicated a significant main effect of alignment, $F(1, 76) = 39.69$, $p < .001$, *partial* $\eta^2 = .34$. Participants were more accurate for aligned pointing judgments ($M = 41°$, $SD = 22°$) than contra-aligned judgements ($M = 70°$, $SD = 39°$). Participants in the low cognitive load group ($M = 46°$, $SD = 23°$) were found to be more accurate in their pointing judgments than participants in the high cognitive load group (M = 65°, SD = 21°), $F(1, 76) = 13.22$, $p < .001$, *partial* $\eta^2 = .19$. Neither the main effect of activity type, $F(1, 76) = .73$, $p = .39$, nor the two-way interaction between activity type and cognitive load was significant, $F(1, 76) = .39$, $p = .54$. No other interactions approached significance (*ps* > .05).

Response latencies showed a reliable effect of alignment, $F(1, 76) = 37.18$, $p < .001$, *partial* $\eta^2 = .33$, such that participants responded to aligned pointing questions (M = 5.6 seconds, SD = 3.4 seconds) faster than contra-aligned questions (M = 7.8, SD = 3.8). A significant cognitive load effect, $F(1, 76) = 4.03$, $p = .048$, *partial* $\eta^2 = .05$, revealed that participants in the low cognitive load group (M = 6.0, SD = 1.8) responded faster than participants in the high cognitive load group (M = 7.4, SD = 4.1). The effect of interactivity was non-significant, $F(1, 76) = .337$, $p = .56$, as was the interaction between activity type and cognitive load, $F(1, 76) = .78$, $p = .38$. All other interactions were not statistically reliable (*p*s > .05).

Drawing Task

Drawing task data was analysed with between-subjects ANOVAs, with activity type (active, passive) and cognitive load (low load, spatial tapping) as factors. Individual analyses were run for subjective ratings, landmark placement errors, and landmark recall.

To obtain subjective ratings, two raters blind to the experimental groups judged participants' maps drawings on a 1-10 scale. Higher scores indicated greater accuracy. Raters' evaluations demonstrated strong reliability, $r(78) = .87$, $p < .001$, and were averaged to a single variable. A main effect of cognitive load, $F(1, 76) = 9.57$, $p = .003$, *partial* $\eta^2 = .112$, demonstrated that the maps from the high cognitive load group (M = 3.8, SD = 2.7) were rated as displaying poorer accuracy than those from the low load group (M = 5.71, SD =

2.62). Both the effect of activity type, *F*(1, 76) = .002, p = .97, and the interaction between activity type and cognitive load, *F*(1, 76) = 2.87, p = .09, were non-significant.

For landmark placement errors, participants in the low cognitive load group produced maps with lower placement errors (*M* = 39mm, *SD* = 19mm) than participants in the high load group (*M* = 59, *SD* = 32), *F*(1, 76) = 11.52, p = .001, *partial* η^2 = .13. The effect of activity type was not significant, *F*(1, 76) = 3.32, p = .07. Likewise, the interaction between interactivity and cognitive load was non-significant, *F*(1, 76) = 1.72, p = .19.

Landmark recall data revealed that participants in the low load group (*M* = .2, *SD* = .4) forgot fewer landmarks than those in the high load group (*M* = .6, *SD* = .9), *F*(1, 76) = 8.14, p = .006, *partial* η^2 = .097. Interactivity produced a marginally significant effect, *F*(1, 76) = 3.41, p = .07, *partial* η^2 = .04, which reflected the finding that passive participants tended to forget fewer landmarks (*M* = .44, *SD* = .25) than active participants (*M* = .53, *SD* = .91). The interaction between activity type and cognitive load was reliable, *F*(1, 76) = 4.76, p = .03, *partial* η^2 = .06 (see Figure 6). Simple main effect tests (with Bonferroni correction) demonstrated that in the low load group, there was no difference between active and passive learners (p = .81), whereas in the spatial tapping group, active learners forgot a greater number of landmarks by comparison with passive learners (p = .006).

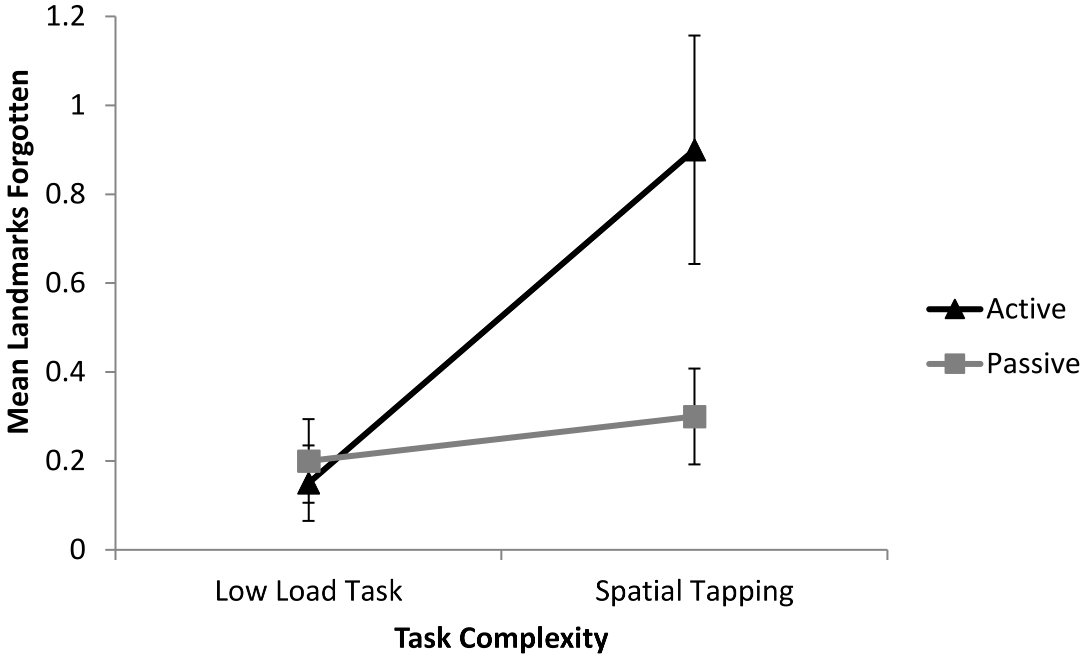

Figure 6. Analysis of landmark recall (mean landmarks forgotten) by cognitive load and interactivity (± standard errors of the mean).

Discussion

The results demonstrate that map learning was detrimentally affected by spatial tapping. Pointing errors and response latencies in the drawing task were lower for the low load group. Likewise, measures of map drawing accuracy showed superior performance in the low load group. The interaction effect in landmark recall demonstrated that in the low load group, there was no effect of interactivity whereas in the spatial tapping group active learners forgot a greater number of landmarks compared to passive learners.

Active learners' reduced ability to recall landmarks while simultaneously conducting spatial tapping suggests that they were unable to cope with increased load as effectively as passive observers. This result is consistent with the notion that activity consumes greater cognitive resources than passive observation (Chrastil & Warren, 2012; Sandamas & Foreman, 2014). The interaction is in agreement with the results observed in Knight and Tlauka (2017), who used an experimental design almost identical to Experiment 1. Knight and Tlauka found that under high load active learners were disadvantaged in three measures of map learning (i.e., pointing errors, subjective ratings, landmark placement error). The present results replicate this finding in landmark recall data. The results suggest that participants in the low load group had greater visuospatial resources available and could hence engage in more effective map learning.

The question arises as to why the active disadvantage was only demonstrated in one measure of map learning, as opposed to three measures in Knight and Tlauka (2017). It is possible that methodological differences between the experiments are responsible. Importantly, active participants in Knight and Tlauka's experiment were required to explore the map by giving verbal commands to the experimenter, who in turn would physically move the sheet of cardboard about the map. Producing verbal commands may have been an unfamiliar experience to active learners and hence caused greater cognitive demand (Sandamas & Foreman, 2007, 2014; Sandamas et al., 2009). In contrast, active learners in the current design were physically in control of map exploration, which may have reduced cognitive demand in comparison to Knight and Tlauka (2017). Consequently, lower cognitive demand associated with physical control in the present design may have decreased the reliability of active disadvantage under high load, because active learners had more cognitive resources available. However, it is also reasonable to argue that physical control of the map was more demanding than giving verbal instructions, given that active learners were required to devote cognitive load to coordinating hand and arm movements. Regardless, the active disadvantage in landmark recall is consistent with the interaction observed in Knight and Tlauka (2017). The results of Experiment 1 therefore reinforce the notion that active learners are disadvantaged if cognitive load is high.

A second important finding of Experiment 1 was that spatial tapping reliably impaired map learning across all dependent measures. This finding is consistent with previous work, suggesting that map learning relies on resources from the visuospatial sketchpad (Coluccia, 2005; Coluccia et al., 2007; Garden et al., 2002). It is noteworthy that participants in Experiment 1 used their feet to conduct spatial tapping. This tapping method deviates from the traditional design, in which participants use their hand to tap cells in the matrix (Quin & Ralston, 1986; Smyth et al., 1988). The current results hence provide evidence that that spatial tapping with one's feet presents a similar burden on visuospatial memory to that of spatial tapping with one's hands.

11. Experiment 2

In Experiment 2, the focus shifted to the phonological loop and the effect of verbal interference on map learning. The investigation of verbal load was motivated by two primary objectives. First, it was unclear if the active disadvantage observed in Experiment 1 was caused by high visuospatial load or by high cognitive demand, in general. Previous work has suggested that spatial tapping demands visuospatial load specifically (Coluccia, 2005; Coluccia et al., 2007; Farmer et al., 1986; Picucci et al., 2013). However interference tasks generally incur modality free cognitive load to some extent, by virtue of splitting attention between two simultaneous tasks (Garden et al., 2002; Rudkin et al., 2007). Given that participants were required to split their attention between map learning and spatial tapping, it is possible that this modality-free demand was responsible for the observed active disadvantage in Experiment 1.

Experiment 2 addressed this possibility by evaluating whether an active disadvantage would also be evident after a high verbal load. If high verbal load leads to an active disadvantage, then this would suggest that active learners are detrimentally affected by modality-free cognitive demand. Conversely, if no active disadvantage were to be found under high verbal load, then it would be concluded that active disadvantage is contingent upon high visuospatial load specifically.

A second motivation for Experiment 2 was to determine if map learning relies on processing in the phonological loop. This goal was independent of our primary interest in verbal load as a moderator of interactivity. As discussed in section 7.3 (p.54), previous work (Coluccia et al., 2006; Garden et al., 2002) has investigated the role of the phonological loop in map learning. However, the results of these experiments diverge with regards to the contribution of the phonological loop. Both Coluccia et al. and Garden et al. found that spatial tapping interfered with map learning to a greater extent than articulatory suppression (i.e., verbal interference). However, Coluccia et al. found that verbal interference had no detrimental effect on map learning whereas Garden et al. showed that verbal interference significantly impaired map recall. These inconsistent results do not provide a coherent answer to the question as to whether high verbal load interferes with acquiring information from maps. Experiment 2 aimed to address this issue by elucidating whether verbal interference impairs map learning.

It should be acknowledged that the verbal interference task used in Experiment 2 would also incur a degree of modality free cognitive demand, inherent in the fact that attention in the high load group would be split between learning the map and verbal interference. Although the generic dual-task demands of split attention are associated with any interference task, cognitive load is increased to a greater extent if the modality of interference overlaps with the modality of the primary learning task (Baddeley, 2002; Garden e al., 2002; Rudkin et al., 2007). Accordingly, a detrimental effect of verbal interference would imply that there are verbal demands in map learning which compete for the limited processing capacity of the phonological loop.

In summary, Experiment 2 was designed to evaluate whether the active disadvantage observed in Experiment 1 would be replicated under verbal (rather than visuospatial) load. Additionally, the experiment examined the effect of verbal interference in map learning. A backwards counting task was used to raise load on the phonological loop (for a similar interference task see Experiment 2, Pazzaglia & Cornoldi, 1999). Active and passive participants took turns counting aloud backwards from 100 in threes such that at a given moment participants were either engaged in speech production or were monitoring their partner's speech production (see procedure below).

Counting aloud has been shown to selectively interfere with verbal encoding (Baddeley & Andrade, 2000) while not impacting visuospatial recall. A backwards counting task was chosen because the executive demands of verbalising a sequence of numbers was thought to closely match that of spatial tapping. Specifically, both spatial tapping and backwards counting require that the learner consciously maintain a sequence (i.e., movements or numbers) in working memory and produce this sequence at a constant rate, which relies on the planning and updating functions of the central executive (Gathercole et al., 2004; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). While conducting spatial tapping, for example, participants touched cells in the tapping matrix in a clockwise motion such that each movement required a discrete response contingent upon his/her place in the tapping sequence (i.e., 'Right, Down, Left, Up'). Likewise, backwards counting required simple arithmetic (i.e., subtraction in threes) which followed a specific sequence (e.g., '97, 94, 91'). As a result, the executive processing associated with planning ahead and updating should have been similar in the interference tasks used in Experiments 1 and 2. Matching executive demands in interference task is beneficial, as any difference between experiments should be attributable to the modality-specific load incurred by visuospatial (i.e Experiment 1) or verbal (i.e., Experiment 2) interference. In contrast, other verbal interference trask such as articulatory suppression (e.g., repeating the word “the” over again) (Baddeley, Allen, & Vargha-Khadem, 2010) do not involve executive processing, and was therefore not considered a suitable comparison to spatial tapping.

The design of Experiment 2 closely resembled that of Experiment 1, except that backwards counting (rather than spatial tapping) was used to raise cognitive load. As in Experiment 1, active and passive participants explored the map via the sheet of cardboard with a hole in the centre. The low load group in Experiment 2 consisted of the same “no interference” participants used in Experiment 1, while new participants were recruited for the backwards counting (i.e., high verbal load) group. Active participants controlled how the map was explored while passive participants observed without verbal or physical involvement in exploration. As in Experiment 1, pointing and drawing tasks were used as measures of map recall.

Method

Participants

Forty participants (31 females, 9 males) took part in Experiment 2 in exchange for $15 or course credit. The low load group consisted of the same participants used in Experiment 1, while the verbal interference group consisted of new participants recruited for Experiment 2.

Procedure

The procedure in the study phase only differed from Experiment 1 in that participants in the high load group performed a backwards counting interference task in the study phase rather than spatial tapping. Participants were instructed to count backwards from one hundred in threes. Active and passive participants were required to complete backwards counting simultaneously, so participants took turns verbalising the sequence, that is, the active participant would state the numbers “97, 94, 91”, and then the passive participant would state “88, 85, 82” etc. Whether the active or passive participant initiated the counting sequence was counterbalanced.

Results

As in Experiment 1, independent sample t-tests showed that dependent measures were unaffected by test order (all *p*s > .22.)

Pointing Task

Analysis of absolute pointing errors revealed a main effect of alignment, $F(1, 76) = 30.68$, $p < .001$, *partial* $\eta^2 = .29$. Participants pointed more accurately from an aligned perspective ($M = 47°$, $SD = 22°$) than from a contra-aligned perspective ($M = 70°$, $SD = 36°$). An effect of cognitive load, $F(1, 76) = 31.78$, $p < .001$, *partial* $\eta^2 = .30$, showed that participants in the low load group ($M = 46°$, $SD = 23°$) were more accurate in their pointing judgments than participants in the verbal interference group ($M = 71°$, $SD = 15°$). Interactivity was not significant, $F(1, 76) = .51$, $p = .48$, nor were any two or three-way interactions (*p*s > .05).

Response latencies revealed a main effect of alignment, $F(1, 76) = 71.45$, $p < .001$, *partial* $\eta^2 = .49$, which demonstrated that participants answered aligned pointing questions ($M = 5.1$ seconds, $SD = 1.7$ seconds) faster than contra-aligned questions ($M = 7.2$, $SD = 3.1$). Both cognitive load, $F(1, 76) = .50$, $p = .48$, and interactivity, $F(1, 76) = .14$, $p = .70$, failed to reach statistical significance. Likewise, all interactions were non-significant (*p*s > .05).

Drawing Task

To acquire subjective ratings, participants' drawings were evaluated by two double-blind raters on a 1-10 scale, on which higher scores indicated greater accuracy. The raters showed strong reliability, $r(38) = .84$, $p < .001$, and their scores were averaged to a single variable.

A main effect of cognitive load on subjective ratings, $F(1, 76) = 29.34$, $p < .001$, *partial* $\eta^2 = .28$, showed that the maps of participants in the low load group ($M = 5.71$, $SD = 2.62$) were rated as more accurate than the maps of participants in the verbal interference group ($M = 3.00$, $SD = 1.79$). In contrast, interactivity did not produce a reliable effect on subjective ratings, $F(1, 76) = 1.75$, $p = .19$. The interaction between cognitive load and interactivity did not approach significance, $F(1, 76) = .39$, $p = .53$.

For landmark placement errors, cognitive load indicated a reliable effect, $F(1, 76) = 45.32$, $p < .001$, *partial* $\eta^2 = .37$. Participants in the low load group drew more accurate maps (M = 39mm, SD = 19mm) than those engaged in verbal interference (M = 75mm, SD = 26mm). The effect of interactivity on placement error was not significant, $F(1, 76) = .009$, $p = .93$, nor was the interaction between cognitive load and interactivity, $F(1, 76) = .44$, $p = .51$

The landmark recall data demonstrated a main effect of cognitive load, $F(1, 76) = 22.16$, $p < .001$, *partial* $\eta^2 = .23$. Participants in the low load group forgot fewer landmarks ($M = .2$, $SD = .4$) than participants in the verbal interference group ($M = .9$, $SD = .8$). Interactivity was not significant, $F(1, 76) = 2.46$, $p = .12$. The interaction between interactivity and cognitive load was also not statistically reliable, $F(1, 76) = 1.49$, $p = .23$.

Discussion

The results from Experiment 2 demonstrated a reliable effect of verbal interference across the dependent measures. In the pointing task, participants in the low load group made judgments more accurately by comparison with those engaged in backwards counting. In the drawing task, the low load group drew maps which were rated as more accurate and displayed greater landmark placement accuracy. Low load participants were also less likely to forget landmarks in comparison to high verbal load participants. No dependent measures revealed an interaction between interactivity and cognitive load.

The primary motivation for Experiment 2 was to determine if the active disadvantage observed in Experiment 1 was caused by a generic increase in cognitive load, or high visuospatial load specifically. High verbal load affected active and passive learners similarly, suggesting active disadvantage in map learning is contingent upon high visuospatial load. It follows that high generic cognitive load does not provide an explanation for the active disadvantage detected in Experiment 1, or in a previously published experiment (Knight & Tlauka, 2017).

The second goal of Experiment 2 was to determine whether map learning demands resources from the phonological loop, as previous research on this topic has been inconsistent (Coluccia et al., 2007; Garden et al., 2002). The present results demonstrated a reliable decrement of verbal inference in map learning, suggesting that the phonological loop contributes to this task. Our findings are in agreement with those of Garden et al. (2002), who also found that verbal interference detrimentally affected map learning. Taking the results of Experiments 1 and 2 together, it is evident that map learning involves multimodal processing which demands input from the visuospatial sketchpad and the phonological loop. This finding is consistent with previous research, which has identified multimodal learning strategies in other spatial learning tasks (Experiment 1, Garden et al., 2002; Hund, 2016; Meilinger, Knauff, & Bülthoff, 2008; Wen, et al., 2011)

Given that map learning is obviously visuospatial, it is worth discussing why verbal resources contribute to this task. A plausible explanation is that a verbal encoding strategy is employed to rehearse the relative locations of landmarks. Specifically, participants may mentally rehearse statements such as “The Shed is southwest of the Fire station”. This strategy would require subvocalisation of landmark relationships, which is not possible while engaged in backwards counting (Baddeley, 1983; Chrastil & Warren, 2012). Verbal interference may have forced participants to rely exclusively on visuospatial encoding, which impaired recall. In contrast, the low load group were free to use a multimodal strategy, which may be beneficial to spatial recall. This explanation is consistent with other research, which has implied that optimal performance in spatial tasks may rely on multimodal learning strategies (Garden et al., 2002; Meilinger et al., 2008; Wen et al., 2011).

The findings of Experiment 2 provide a valuable insight into the role of verbal resources in map learning. Verbal load appears to affect map recall similarly regardless of subjects’ level of interactivity, suggesting that verbal resources are used to the same extent by active and passive learners. This result contrasts with the results of Experiment 1, which showed that visuospatial load selectively impaired the performance of active learners. In conjunction, these results suggest that the active disadvantage found under high visuospatial load is modality specific. Additionally, the results of Experiment 2 support the notion that the phonological loop contributes to map learning (Garden et al., 2002). Garden et al. asked participants to study a number of disjointed segments which, taken together, illustrated a route map of a European city. Participants studied these route segments while completing a visuospatial (i.e., spatial tapping) or verbal interference task (i.e., articulatory suppression). Spatial learning was measured with a recognition task, in which participants identified the correct map segment from a set of three alternatives. The results showed that both interference tasks impaired map recognition compared to no interference. However, spatial tapping reduced performance to a greater extent than articulatory suppression. The results of Garden et al. are in agreement with the current results, which also show a verbal contribution in map learning.

In contrast to Garden et al. (2002), the current investigation used a backwards counting task rather than articulatory suppression to raise verbal load. Articulatory suppression is intended to raise verbal load by requiring the subject to repeat a sequence of syllables, letters, or numbers presented by the experimenter. Verbally repeating a sequence demands verbal resources, thus preventing the phonological loop from rehearsing other information (Baddeley, 1983; Chrastil & Warren, 2012). Following the dual task rationale, tasks which are detrimentally affected by articulatory suppression are assumed to be processed, at least in part, by the phonological loop.

Similar to articulatory suppression, backwards counting achieves the diversion of verbal resources by engaging the phonological loop in task-irrelevant verbalisation (see Pazzaglia & Cornoldi, 1999). However backwards counting also incurs a degree of involvement from the central executive (Gathercole et al., 2004; Lindberg & Gärling, 1982; Baddeley, 2002). In particular, the executive may be involved in mental maintaining arithmetic accuracy in backwards counting (Clearman, Klinger, & Szűcs, 2017). The use of backwards counting therefore raises an important question: Is the effect of verbal interference observed in Experiment 2 reliant on the executive demand associated with backwards counting? Experiment 3 addressed this question by examining the effect of an articulatory suppression interference task in map learning.

Experiment 3

Experiment 2 suggested that verbal resources are used in map learning. The backwards counting task used to reach this conclusion was designed to match the cognitive difficulty of spatial tapping (i.e., tracking and maintaining spatial and temporal accuracy). It is possible that these requirements of spatial tapping demand input from the central executive. Specifically, the executive may be involved in maintaining attention and planning future movements in spatial tapping (Baddeley, 1983; Baddeley, 2002; Miyake et al., 2000; Sandamas & Foreman, 2014). Likewise, the central executive may facilitate refreshing and updating the list of numbers held in working memory during backwards counting (Gathercole et al., 2004; Lindberg & Gärling, 1982; Baddeley, 2002; Miyake et al., 2000; Yang et al., 2016), as previously verbalised numbers are excluded and incoming numbers are calculated (see Clearman et al., 2017). It follows that backwards counting likely demands resources from both the phonological loop and the central executive. As a result, it is impossible to exclude the explanation that the interference effect observed in Experiment 2 is due to central executive demand. This possibility was addressed in Experiment 3, in which participants explored the map while conducting articulatory suppression.

Articulatory suppression involves repeated task-irrelevant verbalisation, impairing one's ability to subvocaliste information (Baddeley et al., 1975; Baddeley, 1983; Chrastil & Warren, 2012; Garden et al., 2002). In addition, previous working memory studies have used articulatory suppression tasks to selectively raise load on the phonological loop (Baddeley, Lewis, & Vallar, 1984; Coluccia et al., 2007; Garden et al., 2002; Yang et al., 2016). Given that articulatory suppression does not involve mental updating or responding to discrete stimuli, no demand should be exerted on the central executive (Yang et al., 2016). Articulatory suppression therefore provides an appropriate test of executive-free verbal interference in map learning.

As no effect of interactivity was found in Experiment 2, it was not expected that interactivity would influence map recall in Experiment 3. This hypothesis follows the rationale that both backwards counting and articulatory suppression are primarily verbal tasks. It follows that the verbal load incurred by articulatory suppression should have no effect on interactivity, as no effect was found following backwards counting. However, it was expected that articulatory suppression would impair map recall overall. A detrimental effect of articulatory suppression would support the suggestion that map learning relies on verbal resources, and rule out the notion that this effect was driven by associated executive demand in Experiment 2. The design of Experiment 3 closely matched that of Experiment 2, except that articulatory suppression was used to raise verbal load.

Method

Participants

Forty subjects (28 females, 12 males) participated in Experiment 3 in exchange for $15 or course credit. These participants were allocated to the articulatory suppression group. Their performance was compared to the low cognitive load control group from Experiment 1.

Procedure

The map learning procedure was identical to previous experiments with the exception that participants conducted simultaneous articulatory suppression while studying the map. To perform articulatory suppression, participants repeatedly verbalised the word “the” approximately once per second for the duration of the study phase. The experimenter encouraged the active and passive participant pronounce the word in unison and ensured participants could maintain consistent and clear articulation. The articulatory suppression procedure follows the work of previous research in working memory (see Baddeley, Allen, & Vargha-Khadem, 2010; Baddeley et a., 1984; Irrazabel, Saux, & Burin, 2016), in which repeated verbalisation of irrelevant words has been used to raise verbal load.

Results

Independent sample t-tests reported that all dependent measures (except landmark recall) were unaffected by order of testing in the pointing task (all *p*s > .07). Landmark recall data showed that participants tested second forgot fewer landmarks than participants tested first, t(64.90) = 2.09, *p* = .04, *d* = .47.

Pointing Task

The analysis of absolute pointing errors revealed an alignment effect, *F*(1, 76) = 44.84, *p* < .001, *partial* η^2 = .37. Participants pointed more accurately from an aligned perspective (*M* = 38°, *SD* = 21°) than from a contra-aligned perspective (*M* = 65°, *SD* = 36°). A significant main effect of cognitive load was found, *F*(1, 76) = 5.07, *p* = .027, *partial* η^2 = .06, such that participants in the low load group (*M* = 46°, *SD* = 23°) were more accurate in their pointing judgments than participants in the articulatory suppression group (*M* = 58°, *SD* = 21°). Interactivity was not significant, *F*(1, 76) = .13, *p* = .72, and no interactions approached significance (*p*s > .05).

For the response latency data, a significant alignment effect was found, *F*(1, 76) = 61.70, *p* < .001, *partial* η^2 = .45. Participants answered aligned pointing questions (*M* = 5.1 seconds, *SD* = 1.7 seconds) faster than contra-aligned questions (*M* = 7.3, *SD* = 3.3). Both, cognitive load, *F*(1, 76) = .40, *p* = .53, and interactivity, F(1, 76) = .30, *p* = .59, were not significant. No interactions were significant (*p*s > .05).

Drawing Task

Subjective ratings were acquired in the same way as Experiments 1 and 2, by two double-blind raters evaluating participants' drawings on a 1-10 scale, with higher scores indicating greater accuracy. The raters' evaluations were strongly correlated, *r*(38) = .90, *p* < .001 and the scores were averaged to a single variable.

Subjective ratings showed that the main effect of cognitive load was significant, *F*(1, 76) = 7.75, *p* = .007, *partial* η^2 = .09. The maps of low load participants (*M* = 5.71*, SD* = 2.62) were rated as more accurate than maps of participants in the verbal interference group (*M* = 4.14, *SD* = 2.44). In contrast the effect of interactivity was not reliable, *F*(1, 76) = .16, *p* = .69. The interaction between interactivity and cognitive load did not approach significance, *F*(1, 76) = 1.76, *p* = .19.

For landmark placement errors cognitive load produced a significant effect, *F*(1, 76) = 16.89, *p* < .001, *partial* η^2 = .18. The low load group drew more accurate maps (*M* = 39mm, *SD* = 19mm) than the articulatory suppression group (*M* = 61mm, *SD* = 27mm). Interactivity did not indicate a reliable effect, *F*(1, 76) = 1.36, *p* = .25, nor did the interaction between interactivity and cognitive load, *F*(1, 76) = .36, *p* = .55

The landmark recall data revealed that cognitive load significantly affected landmark recall, *F*(1, 76) =15.16, *p* < .001, *partial* η^2 = .17, as fewer landmarks were forgotten by the low load group (*M* = .2, *SD* = .4) in comparison to the articulatory suppression group (*M* = .8, *SD* = .8). Interactivity did not lead to a significant effect, *F*(1, 76) = .03, *p* = .87, and the interaction between interactivity and verbal load was also not significant, *F*(1, 76) = .26, *p* = .61.

Discussion

The results from Experiment 3 demonstrated a consistent detrimental effect of verbal load, similar to the results of Experiment 2. In the pointing task articulatory suppression impaired accuracy. However, no effect of verbal load was observed on response times. In the drawing task, subjective evaluations and drawing errors were negatively affected by articulatory suppression by comparison with no interference. Those engaged in articulatory suppression also forgot to include a greater number of landmarks in map drawings compared to low load participants. As in Experiment 2, no measures revealed an interactivity effect or an interaction between interactivity and verbal load. These results are consistent with those obtained in Experiment 2, suggesting that map learning relies on the phonological loop.

The purpose of Experiment 3 was to determine whether verbal interference without associated executive demand would impair map learning. This research objective followed the rationale that both backwards counting (Experiment 2) and spatial tapping (Experiment 1) rely on input from the central executive (Yang et al., 2016). Specifically, spatial tapping and backwards counting require maintained attention and forward planning, which are functions of the central executive (Baddeley, 1983; Baddeley, 2002; Sandamas & Foreman, 2014). As a result, it was possible that executive load rather than modality specific load (i.e., visuospatial and verbal) was responsible for the interference effect observed in Experiments 1 and 2. The results of Experiment 3 demonstrated that map learning was impaired by simple repetition of an irrelevant word, a verbal task which does not require processing in the central executive. Consequently, executive demand does not provide a sufficient explanation for the results observed in Experiment 2. In contrast, the present results suggest that map learning relies on verbal resources, regardless of the presence (i.e., Experiment 2) or absence (i.e., Experiment 3) of associated executive demand.

12. Experiment 4

In Experiment 4, the focus shifted to the central executive component of working memory. The executive facilitates the functions of working memory which are not specific to a particular modality (i.e., visuospatial or verbal information). Such functions include integrating information from the subcomponents in multimodal tasks, shifting attention, problem solving, updating representations, and applying working memory in decision making (Baddeley, 1983; Baddeley, 2002; Miyake et al., 2000). The contribution of executive functions in map learning has not been investigated previously. However, research into spatial learning stimuli other than maps suggests that executive memory plays a role in visuospatial learning (Ang & Lee, 2008), particularly in sequential tasks (Rudkin et al., 2007).

The primary objective of Experiment 4 was to identify whether active and passive map learners are equally affected by executive interference. Experiments 2 and 3 demonstrated that verbal load equally affected learners regardless of their level of interactivity. This finding suggested that the active disadvantage observed in Experiment 1 was the result of high visuospatial load rather than a generic increase in cognitive demand. If high visuospatial load is indeed responsible for the active disadvantage, then no active disadvantage should be observed following high executive demand.

It is possible, however, that active learning demands greater executive resources than passive observation (Coluccia, 2005; Taillade et al., 2013). If this were the case, then an active disadvantage following high executive load should be found. A possible contribution of the executive in active learning was demonstrated by Vecchi and Cornoldi (1999). The authors had old and young participants perform active and passive spatial exercises. Passive exercises included a visual imagery task in which participants were presented with an array of a simple image (e.g., a green circle above a red cloud) for two seconds. Participants were required to draw the studied image, retaining the objects' colours and spatial properties. Passive memory span was calculated by the maximum number of objects participants could recall without error. Active tasks included a puzzle task in which participants were required to study an image that was divided into a number of fragments (i.e., puzzle pieces). Each image fragment was allocated a unique number. A matrix was also presented to participants which contained cells equal to the number of fragments in the puzzle (i.e., 4, 6, 9, 12, or 16 cells). The goal was to write numbers into each cell of the matrix such that the corresponding image fragments would form the correct picture (see Figure 7). Active memory span was measured by recording at which point participants could no longer successfully solve the puzzle (i.e., the number of cells in the matrix).

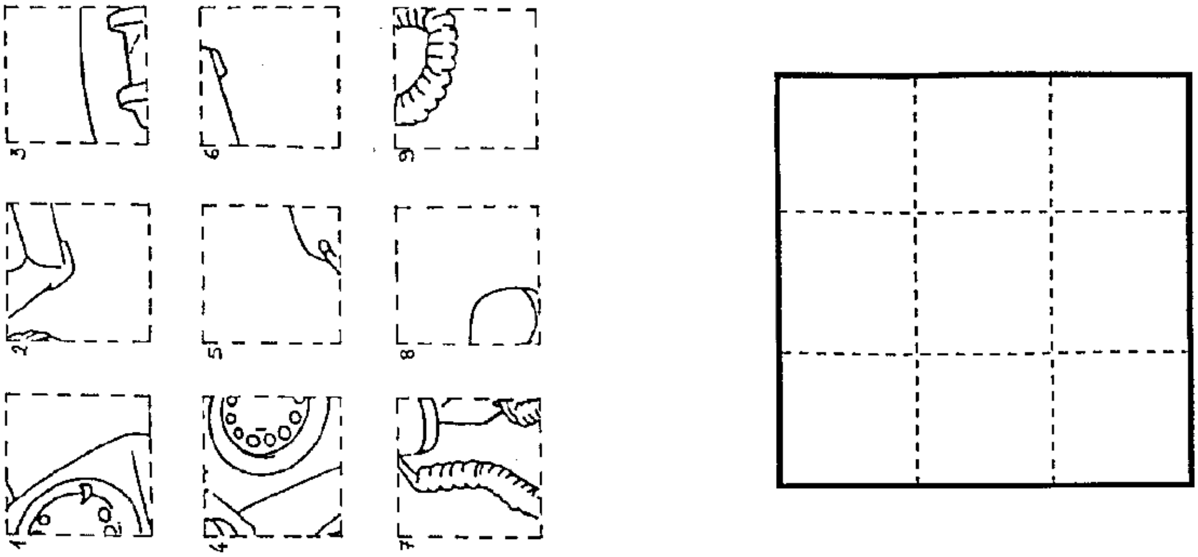

Figure 7. Puzzle matrix task by Vecchi & Cornoldi (1999)

The results showed that older participants performed significantly worse than younger participants in active visuospatial tasks, whereas performance in passive tasks was less affected by age. The authors argued that the discrepancy in performance for active tasks was associated with age-related executive decline in the elderly participants. Specifically, it was suggested that active spatial learning demands greater allocation of executive resource than passive observation. It follows that age-related executive decline may be associated with decline in active visuospatial ability. In comparison, young participants were able to maintain greater performance in active tasks, presumably due to a more functional executive memory. In the current design, it is possible that executive resources would be in greater demand by active learners due to the necessity to plan movement of the cardboard and make decisions regarding map exploration. It was therefore possible that active learners may be negatively affected by executive interference to a greater extent than passive observers.

A secondary goal of Experiment 4 was to determine if the central executive contributes to map learning in general, as previous research has not investigated the contribution of the executive in this field. Map learning requires that the learner integrate new information into an existing mental representation. Two-dimensional information acquired form a map must also be transformed to a format applicable to the pointing task, which requires egocentric judgements of direction (Montello, 2010). These functions may be facilitated by the executive, which manages integration and transformation of information. The central executive is also involved in coordinating and combining visuospatial and verbal information in multimodal tasks. Given that Experiments 1-3 demonstrated that map learning is a multimodal exercise, it may be expected that the executive plays a role in map learning.

The experimental design of Experiment 4 was similar to Experiments 1-3, albeit a different interference task was used. To target the central executive, participants in the high load group were required to perform an *n*-back task while learning the map. Participants were presented with a sequence of letters and were required to judge if certain letters had previously appeared. The *n*-back task required that participants maintain attention to the letter sequence and make explicit decisions, as each letter demanded a discrete “yes” or “no” response. Sustained attention and decision making are managed by the central executive (Baddeley, 1983). Additionally, executive resources are involved in monitoring and updating incoming information (Miyake et al., 2000), an ability crucial for the *n*-back task (Baune, Czira, Smith, Mitchell, & Sinnamon, 2012). The *n*-back task thus demands load from several key functions of the executive (i.e., attentional maintenance, decision making, updating information). For more details on the *n*-back task, see Morris and Jones (1990).

Method

Participants

Forty university students volunteered to participate in Experiment 4 (11 males, 29 females), and were awarded with course credit or $15. These participants completed the *n*-back task while learning the map, while the low load group comprised participants from Experiment 1.

Procedure

The experimental design was similar to the previous experiments with the exception that the *n*-back task was used to raise cognitive load. In addition to the standard instructions to learn the map, participants in the *n*-back group received additional task-specific instructions. The experimenter explained that he would read aloud a sequence of letters to participants. Participants were asked to attend to the sequence, so they could state whether each letter matched or did not match the letter presented two spaces before (i.e., a 2-back design). The experimenter asked participants to respond with "yes" if the letter did match, and "no" if the letter did not match. Active and passive learners completed the *n*-back task simultaneously, so the pair of participants interchanged responses after every second letter. For instance, when presented with the sequence "G, R, G, O, S, O" the active participant would respond "yes" to the third letter in the sequence (G) because this letter matched that which came two spaces before, but would answer "no" to the fourth letter (O) because this was preceded two spaces before by the letter "R". The second participant would then respond to the next two letters (i.e., "S" and "O"). Participants would continue interchanging responses after every second letter for the duration of the study phase. The study phase was initiated once participants were able to complete a 10-letter practice sequence without error. During the study phase the experimenter would point out any errors to participants to ensure focus was maintained on the *n*-back task. After studying the map while conducting the *n*-back task, participants completed the pointing and drawing tasks.

Results

Independent samples t-tests showed that the order of testing in the pointing task did not affect performance (all *p*s > .05).

Pointing Task

Pointing errors demonstrated an effect of alignment, $F(1, 76) = 25.77$, $p < .001$, *partial* $\eta^2 = .25$. Participants responded more accurately to aligned questions ($M = 32°$, $SD = 18°$) than contra aligned questions ($M = 55°$, $SD = 34°$). An effect of cognitive load, $F(1, 76) = 14.71$, $p < .001$, *partial* $\eta^2 = .16$, showed that participants in the *n*-back group ($M = 66°$, $SD = 21°$) pointed less accurately than participants in the low load group ($M = 46°$, $SD = 23°$). The effect of interactivity was not statistically reliable, *F*(1, 76) = .382, *p* = .53, and no two or three-way interactions were significant (*ps* > .05).

For response latencies, the main effect of alignment was significant. Participants responded faster to aligned pointing questions (*M* = 5.3 seconds, *SD* = 2.3 seconds) than contra-aligned questions (*M* = 7.46, *SD* = 3.51), *F*(1, 76) = 59.31, *p* < .001, *partial* η^2 = .44. Neither cognitive load, *F*(1, 76) = 1.67, *p* = .20 nor interactivity, *F*(1, 76) = .38, *p* = .54, revealed significant effects. Likewise, all interactions were non-significant (*p*s > .05).

Drawing Task

As in the previous experiments, two raters provided subjective evaluations of participants' maps on a 1-10 scale, with higher scores indicating greater accuracy. The obtained map ratings were strongly correlated, *r*(38) = .80, *p* < .001, and were averaged into a single variable. The effect of cognitive load was found to be statistically reliable, *F*(1, 76) = 38.74, *p* < .001, *partial* η^2 = .34, demonstrating that the maps of participants in the *n*-back group (*M* = 2.61, *SD* = 1.80) were considered less accurate than the maps of participants in the low load group (*M* = 5.71, *SD* = 2.62). The effect of interactivity was not significant, *F*(1, 76) = 3.45, *p* = .07, nor was the interaction between activity type and cognitive load, *F*(1, 76) = .010, *p* = .920.

Landmark placement errors showed a reliable effect of cognitive load, *F*(1, 76) = 37.54, *p* < .001, *partial* η^2 = .33. Those in the *n*-back group (*M* = 77mm, *SD* = 33mm) produced inferior maps compared to those in the low load group (*M* = 40mm, *SD* = 20mm). Interactivity did not indicate a significant effect, *F*(1, 76) = .22, *p* = .64, or interact with cognitive load, *F*(1, 76) = .90, *p* = .35.

Landmark recall data also showed a significant effect of cognitive load, *F*(1, 76) = 14.60, *p* < .001, *partial* η^2 = .16. Low load subjects (*M* = .2, *SD* = .4) forgot significantly fewer landmarks than subjects engaged in executive interference (*M* = .7, *SD* = .4). Landmark recall was not affected by interactivity, *F*(1, 76) = .48, *p* = .49, and the interaction between interactivity and executive load was not significant, *F*(1 , 76) = .12, *p* = .73.

Discussion

The results of Experiment 4 demonstrated a reliable detrimental effect of executive interference. In the pointing task participants showed higher pointing errors and response times while engaged in the *n*-back task relative to the low load participants. Likewise, participants' map drawings were detrimentally affected by executive interference, a finding which was evident in subjective evaluations, landmark placement, and landmark recall. As in Experiments 2 and 3, no measures detected an interaction between interactivity and cognitive load.

The primary aim of Experiment 4 was to determine if executive load would lead to an active disadvantage similar to that observed in Experiment 1. The results showed that the effect of executive interference in active and passive learners was similar. It follows that that active learning did not demand additional executive resources by comparison with passive observation, as executive load failed to selectively disadvantage active learners. The results of Experiment 4 support the assertion that an active disadvantage in map learning is contingent upon high visuospatial load and is not caused by a generic increase in cognitive demand.

The comparable effect of executive interference regardless of participants' level of interactivity is not consistent with Vecchi and Cornoldi (1999), who suggested that executive resources are in higher demand by active learners. Recall that Vecchi and Cornoldi asked young and old subjects to complete active (e.g., puzzle solving) and passive (e.g., Corsi

Blocks) visuospatial tasks. The results showed performance in active tasks was impaired to a greater extent in older subjects, which the authors attributed to age-related executive decline. Specifically, it was suggested that active learning requires greater manipulation and rehearsal of information than passive observation, and hence requires input from the executive.

The present results are not consistent with Vecchi and Cornoldi’s (1999) conclusion. In contrast, the results of Experiment 4 suggest executive load is incurred to a similar degree by passive and active map learning, as executive interference was equally disruptive regardless of subjects’ level of interactivity. One explanation for this finding is that the demands of passive map learning in the current scenario demanded greater executive input than the passive tasks used in Vecchi and Cornoldi’s experiment, which leads to passive participants being impaired to similar degree as active participants. In the current experiment, passive participants were required to flexibly adapt to the exploration path chosen by the active participant (Miyake et al., 2000). Cognitive flexibility is managed by the central executive (Miyake et al., 2000). It is hence possible that the requirement for passive learners to adapt their survey learning to an exploration path controlled by a partner raised executive demand in passive observers. In contrast, the passive tasks used in Vecchi and Cornoldi’s experiment were manipulated by the subjects and hence may not have demanded the same degree of cognitive flexibility. Consequently, executive load in passive learners may have been higher in the current experiment than in Vecchi and Cornoldi’s study. With respect to active participants, executive load may have been incurred by the forward planning and decision making involved in moving the sheet of cardboard to explore the map (Gathercole et al., 2004; Hitch & Baddeley, 1976). It should be acknowledged that the present study did not investigate age directly. Age differences in participant samples could explain the discrepant outcomes of the current experiment and Vecchi and Cornoldi, however investigating age effects was outside the scope of this thesis.

A secondary goal of Experiment 4 was to determine if map learning is reliant upon resources from the central executive. Reliable main effects in the pointing and drawing tasks demonstrated that executive load reliably diminished map learning ability, suggesting that the central executive is involved in map learning. A plausible explanation for the role of the executive in map learning is derived from the results of Experiments 1-3. These experiments demonstrated that visuospatial and verbal resources are used in map learning, suggesting that people encode information from maps using multimodal strategies. One of the primary functions of the central executive is to combine and coordinate information in multimodal tasks (Gathercole et al., 2004; Baddeley, 1983; Baddeley, 2002; Hitch & Baddeley, 1976). Given the multimodal learning strategies evident in Experiments 1-3, one interpretation of the present findings is that the executive contributed to map learning by coordinating visuospatial and verbal information.

In summary, the primary implications for Experiment 4 are as follows. Active and passive learners are both detrimentally affected by executive interference, possibly due to the executive demands of passive (i.e., cognitive flexibility) and active (i.e., forward planning) map learning. This result suggests that high executive demand does not influence the effect of interactivity in map learning. The deterioration of map recall following executive interference also suggests that map encoding relies on the central executive resources to coordinate multimodal (i.e., visuospatial and verbal) learning.

13. Experiment 5

Experiments 1-4 used a free exploration design, in which participants were asked to learn the map, knowing that their spatial understanding would be evaluated in future tests. In real world settings, maps are rarely used as a means to simply improve one's general spatial memory for an environment. Rather, maps are typically studied to aid navigation between a particular starting point and destination (Montello, 2010). An important question is therefore raised: does goal-driven learning alter the effect of interactivity and cognitive load on map learning? Goal-driven learning is important to consider as it could be argued that "active" map learning is primarily exercised in the pursuit of a specific goal. This is because when navigating toward a destination, the learner is required to consciously determine the most accurate route and monitor their position to ensure he/she does not deviate (Meilinger, Franz, & Bülthoff, 2012). It is hence possible that actively navigating with maps could exert unique demands on working memory which are not required if maps are freely explored (i.e., Experiments 1-4).

Experiment 5 was motivated by two primary interests. The first motivation was to evaluate the effect of interactivity in a more applied context, in which participants pursue a specific navigational goal. The second motivation was to assess whether the presence of navigational goals would influence map learning in active and passive subjects. If goal driven navigation alters the effect of interactivity, this could provide an explanation for differences between interactivity experiments which focus on navigational goals (e.g., Attree, 1996) and those which focus on free navigation (e.g., Wallet et al., 2011).

Several experiments on goal driven navigation have used a design in which subjects are required to select the most efficient route between two points (Brunyé, Mahoney, Gardony, & Taylor, 2010; Fu, Bravo, & Roskos, 2015). This procedure mirrors the manner in which maps are commonly used in navigation, i.e., in order to determine the most efficient route to a goal. Research on path choice has indicated that participants are prone to engage in heuristics which simplify the learning process, potentially at the cost of making correct decisions. One such heuristic is the “least angle bias”, which describes the tendency for participants to preferentially select the path which initiates in the direction of the destination, even though initial path direction may not be indicitative of absolute path length (Fu et al., 2015). The least angle bias can cause people to overemphasise initial path direction at the expense of appraising the efficiency of the centre and end sections of a route. In map learning specifically, the least angle bias could cause participants to focus attention on areas of the map near the beginning of paths, which could have an overall negative effect on spatial recall of the map (Wilson & Wildbur, 2004).

Brunyé et al. (2010) investigated a second bias which relates directly to path choice in map learning. Specifically, the authors investigated subjects’ path choice for a journey set on a horizontal axis (i.e., “east to west” or “west to east”). In several experiments, Brunyé et al. had participants choose one of two equal length routes to a destination. One path travelled in a generally northward direction while the other travelled generally southward. The results demonstrated a bias to choose southern paths, only if participants were asked to take an egocentric perspective (i.e., to imagine themselves standing on the path) rather than an allocentric perspective (i.e., imagining the path from a “bird’s eye” perspective). These findings suggested path choice was affected by participants’ personal preferences as opposed to the spatial properties of the path. Subsequent experiments evaluated participants’ subjective decision criteria and found that participants equated southern paths with travelling downhill while northern paths were viewed as uphill journeys. Consequently, northern paths were associated with greater physical effort and were viewed as taking longer to traverse than southerly paths of equal length (Experiment 6). The southern path bias demonstrates that subjective bias in path choice can play a role in the acquisition of spatial knowledge from maps.

It is possible that heuristics including the “least angle” and southerly bias apply to a greater extent if the subject is responsible for navigation. Active learners, by definition, are required to make decisions regarding where to explore and to execute the associated physical movement. It follows that activity may encourage heuristics because active learners are encouraged to consider optimal navigational strategies. In contrast, passive viewing does not engender consideration of navigational choices and therefore may not encourage biases. If activity encourages the use of heuristics in goal-driven map learning, then it should be expected that active learners will demonstrate impaired path choice compared to passive learners. Here “path choice” is used to describe the process of evaluating the most spatially efficient route among several alternatives. In Experiment 5, path choice was measured by asking participants to select which path from a set of three was the most spatially efficient route between a westerly and easterly landmark (see method details below). It was expected that active participants would fail to identify the optimal route more often than passive participants. Given that Experiment 1 only revealed a difference between active and passive groups in the high load task, it was expected that activity would only be detrimental to goal-driven map learning if cognitive load was raised with a visuospatial interference task (i.e., spatial tapping). Conversely, no effect of interactivity was expected when the goal-driven map was explored without interference

The results of Experiments 1-4 demonstrated a reliable main effect of concurrent interference during map learning regardless of the modality of load imposed. In Experiment

5, it was expected that goal-driven map exploration would be similarly affected by concurrent interference such that high load would reduce participants' ability to navigate towards a goal. Fu et al. (2015) reported results consistent with this expectation. Participants completed a goal-driven spatial learning exercise under high or low cognitive load. Specifically, subjects were required to walk to a number of tables from a fixed starting point in the room. In Experiment 1, all destinations along the route were visible for the entire duration of exploration. In Experiments 2 and 3, participants were shown a diagram of the route prior to exploration. During route traversal, however, each destination along the route could only be seen once participants located intermediary destinations. As a result participants were required to visualise the route in working memory, which increased cognitive load. To evaluate path choice, the researchers recorded whether participants chose to initiate movement along one of two possible paths (i.e., a left or rightwards bias).

The results showed that participants were biased to initiate movement in the direction of the final destination, despite the fact that both paths to the first destination were of equal length. However, this relationship became weaker as cognitive demand was increased (i.e., Experiments 2 and 3). The authors concluded that high cognitive demand may have negatively affected participants ability to visualise the location of the final destination of the route. It was further inferred that cognitive load may influence other aspects of spatial learning including the integration of discrete routes into a larger representation (i.e., survey learning). The results of Fu et al. (2015) therefore suggest that goal driven learning may be sensitive to manipulation of cognitive load, supporting the present investigation of this notion in the map learning domain. Furthermore, the question is raised as to whether the active disadvantage under high load will be maintained under goal driven exploration, given the specific costs of cognitive demand in goal driven learning.

To accommodate a goal driven map learning design, the map explored in Experiment 5 incorporated three visually distinct paths. Participants were asked to determine which of the three paths was the most efficient route connecting two landmarks which were placed on opposite sides of the map. Active participants controlled how these paths were explored by manipulating the sheet of cardboard to view the map in the same way as Experiments 1-4. Past research has indicated that paths which contain a greater number of turns (Bailenson et al., 1998, 2000) or landmarks (Seneviratne & Morrall, 1985) are viewed as longer than paths with fewer turns or landmarks. Consequently, all paths incorporated the same number of turns and intersected an equal number of landmarks. To raise cognitive load, participants completed the same spatial tapping interference task used in Experiment 1. Participants studied one of two possible maps in Experiment 5, both of which contained paths to facilitate goal-driven learning. The new map was incorporated to ensure potential effects were not attributable to a particular map, a possibiltiy that was not controlled in Experiments 1-4. For a similar counterbalancing procedure, see Experiment 3 in Coluccia et al. (2007)

It was predicted that interactivity and cognitive load would interact. Specifically, high visuospatial load was expected to disadvantage active participants whereas passive participants were expected to maintain learning despite high load. This hypothesis was driven by the assumption that activity demands greater cognitive resources than passive observation, and hence active learners may not be able to cope with increased cognitive demand (Knight & Tlauka, 2017). It was expected that the spatial biases inherent in goal driven designs would accentuate this active disadvantage as active learners engage with navigation to a greater extent and may therefore be more susceptible to spatial biases and heuristics than passive observers. The expectation for an active disadvantage will be tested with a path choice measure in Experiment 5 as well as the pointing and drawing tasks used previously in Experiments 1-4. Additionally, it was hypothesised that high visuospatial load would have an overall detrimental effect on goal-driven map learning (Coluccia et al., 2007; Garden et al., 2002; Knight & Tlauka, 2017).

Method

Participants

Eighty participants volunteered for Experiment 5 (27 Males, 53 Females) and were awarded with course credit or $15.

Materials

Experiment 5 utilised two unique maps (Figures 8 and 9), which were counterbalanced across groups. Of these two maps one was the same used in Experiments 1-4 while the other was a new map. The new map matched the map used previously in art style, size, and visual features. However, the new map contained novel landmarks and landmark locations. Both maps incorporated three distinct paths, which all initiated from a landmark on the western side and concluded at an easterly landmark. Bold yellow, blue and red colours were used to depict the paths, to ensure that each retained unique salient visual properties. On both maps, the paths were non-symmetrical routes which intersected several landmarks and stayed within approximately the same third of the map (i.e., upper, middle, bottom). The paths began by moving directly northwards, then diverging in different easterly directions. The total length of each path (i.e., distance between the initial and final landmark) was not equal. To depict these paths in the drawing task, three coloured pens and a black pen were provided for partcipants. The coloured pens matched the colours of the paths (i.e., yellow, blue and red), to ensure that participants were able to depict the paths as accurately as possible in the drawing task. The black pen was used to indicate landmarks.

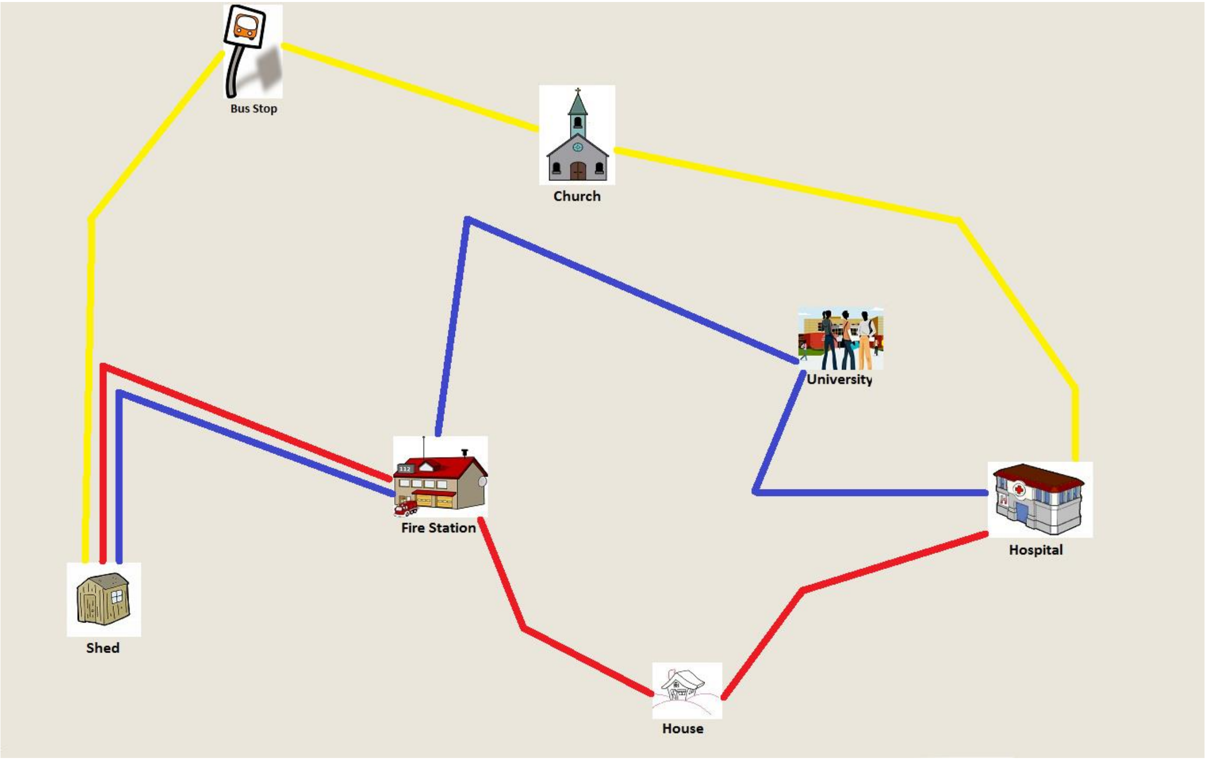

Figure 8. One of the two maps participants were allocated to study in Experiment 5. This map is nearly identical to that used in Experiments 1-4, albeit paths were incorporated.

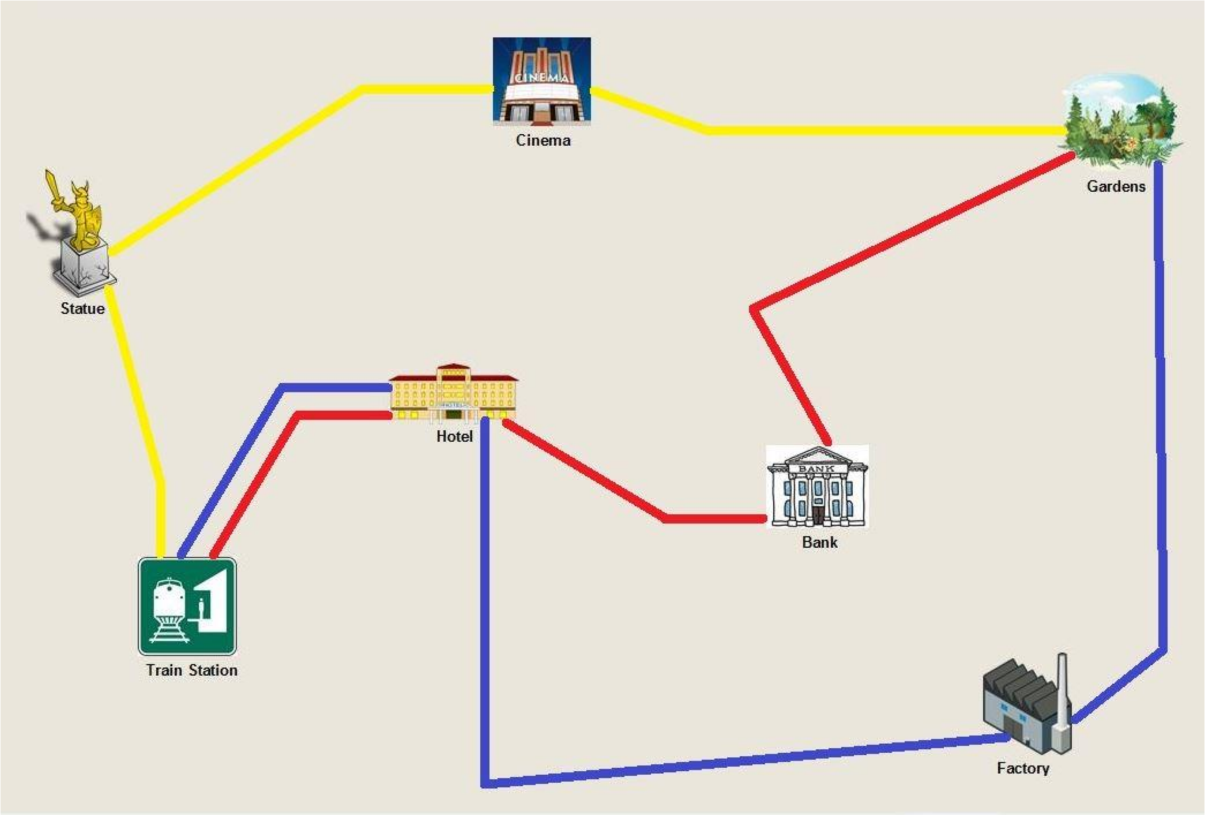

Figure 9. One of the two maps participants were allocated to study in Experiment 5. This map was new and was designed to match the visuospatial properties of the map used previously (Figure 8).

Procedure

Study Phase

In the study phase, participants viewed one of the two available maps, which were counterbalanced across groups. Participants received the same instructions that were given in Experiments 1-4, that is, participants were informed about their role to either control map exploration (active) or to observe this process without communication (passive). Participants were informed that their task was to learn the spatial layout of the map. An additional set of instruction were given with regards to the goal driven component of Experiment 5. Specifically, participants were informed that three paths travelled between a landmark on the west side of the map to a landmark on the east side of the map.

Participants' task was to determine which of the three paths was the most efficient route from the starting landmark to the destination landmark. To emphasise the importance of route choice, participants were asked to imagine that they would be required to drive along one of the paths, so choosing the shortest path was desirable. Participants were asked to make their choice of route individually and not to reveal or discuss their choice with their partner in the experiment. To begin map exploration the hole in the sheet of cardboard always revealed the westerly landmark from which the paths initiated (i.e., the shed or train station) to ensure all participants explored from the same starting point. Participants in the high load group were instructed in how to perform the spatial tapping task while exploring the map. As in the previous experiments, participants were provided 2.5 minutes to explore the map.

Testing Phase

The pointing task was carried out in an identical fashion to the previous experiments, albeit new pointing questions were devised for the new map. The new pointing questions matched those used for the old map as closely as posisible and followed previous counterbalancing procedures. These procedures included posing an equal number of aligned and contra aligned questions and ensuring that questions required an equal number of leftward and rightward responses.

The drawing task procedure was alterred to accommodate the new maps. As in the earlier experiments, participants were asked to draw the studied map as accurately as possible. Emphasis was given to maintaining the correct spatial relationships between landmarks as visual details (e.g., the colour of landmarks) was not important. A new set of instructions asked participants to depict the paths with three coloured pens, each of which matched the colour of a path (i.e., a yellow, blue, or red pen). Participants were encouraged to accurately convey the length of each path and ensure paths intersected the correct landmarks. Participants were asked to indicate the path which they believed to be the most efficient route from start to finish on the top-right corner of their map. On both maps, the correct choice was the red path. The colour of the optimal path was identical in both maps to ensure that different colours could not account for any differences in path choice between the two maps (though no differences between maps were expected). As before, participants were given 1.5 minutes to complete map drawings. One might expect that this time limit should have been increased to allow for the complexity of including the paths. However, the 1.5 time limit was rarely required for completion of map drawings in previous experiments, suggesting that the drawing task in Experiment 5 could be completed within the alloted time.

The presence of paths in the map drawing task afforded two new measures of spatial learning: path error and path choice. Path error was a measure of the absolute difference in length of participants' depicted paths in comparison to the paths presented on the studied map. To obtain path error, the three paths on participants' drawings were individually measured with a ruler. If paths were depicted in curved, rather than straight, lines, then a length of string was placed along the path. The string was then elongated and placed on a ruler to determine the equivalent straight-line distance of the curved path. The mean absolute deviation (in mm) of all three paths was used to determine a "path error" score for each participant. Path choice was recorded as a dichotomous ("correct or incorrect") response as to whether participants were able to determine that the red path was the most efficient route from start to finish. Choosing either blue or yellow consistituted an "incorrect" response.

The only difference between Experiment 5 and Experiment 1 was the presence of goal-driven learning instructions and salient paths in Experiment 5. Both experiments manipulated interactivity and manipulated visuospatial load with a spatial tapping interference task. Accordingly, comparing the data from Experiments 5 and 1 provided a test for the effect of goal-driven (i.e., Experiment 5) vs. free exploration (Experiment 1). This between-experiment analysis is presented after the standard results section for Experiment 5 below.

Results

As in Experiment 1-4, independent samples t-tests were used to test whether performance was affected by order of testing in the pointing task. The results showed no difference in the map recall of participants tested first and second (all *p*s > .36). Additional preliminary analyses with independent samples t-tests evaluated whether there was any difference in map recall between the original map (Figure 8) and the new map employed as a counterbalancing measure in Experiment 5 (Figure 9). The analyses reported no significant differences in recall between maps (all *p*s > .05).

Pointing Task

As in the previous experiments, the data from the pointing task were analysed with mixed analyses of variance (ANOVAs). Interactivity (active, passive) and cognitive load (low load, spatial tapping) were experimentally manipulated between subjects. Alignment (aligned, contra-aligned) was a within subjects variable.

Pointing errors showed a reliable alignment effect, $F(1, 76) = 46.45$, $p < .001$, *partial* $\eta^2 = .38$. Aligned pointing judgments ($M = 31°$, $SD = 18°$) were made with greater accuracy than contra-aligned judgments ($M = 55°$, $SD = 34°$). Cognitive load was not statistically reliable, *F*(1, 76) = 2.30, *p* = .13. Likewise the effect of interactivity on pointing errors was not significant *F*(1, 76) = .23, *p* = .63, nor was the interaction between cognitive load and interactivity *F*(1, 76) = .18, *p* = .67.

Response latency data revealed a significant alignment effect, *F*(1, 76) = 12.33, *p* = .001, *partial* η^2 = .38. Aligned questions were answered more quickly (*M* = 5.7seconds, *SD* = 4seconds) than contra aligned questions (*M* = 7.4, *SD* = 3.4). Both interactivity, *F*(1, 76) = .27, *p* = .61, and cognitive load, *F*(1, 76) = .06, *p* = .82, were not significant, and the interaction between these variables was also non-significant, *F*(1, 76) = .01, *p* = .91.

Drawing Task

Data for the drawing task was tested with between-subjects ANOVAs. Interactivity (active, passive) and cognitive load (low load, spatial tapping) were entered as factors. Discrete analyses were run for subjective ratings, landmark placement errors, landmark recall and path error. Chi-square analyses were used to evaluate whether interactivity and cognitive load significantly affected route choice (i.e., whether or not participants correctly identified the most efficient route).

Subjective ratings were obtained from two judges who were blind to the experimental groups. The judges' ratings were strongly correlated, *r*(78) = .82, *p* < .001, and averaged into a single variable. Cognitive load demonstrated a significant effect on subjective ratings, *F*(1, 76) = 19.58, *p* < .001, *partial* η^2 = .21. The maps of participants in the spatial tapping group (*M* = 4.89, *SD* = 2.28) were rated as less accurate than those of the low load group (*M* = 7.25, *SD* = 2.43). Interactivity did not produce a consistent effect, *F*(1, 76) = .01, *p* = .91, nor did the interaction between interactivity and cognitive load, *F*(1, 76) = .07, *p* = .80.

Analysis of the landmark placement data showed that cognitive load was not significant, *F*(1, 76) = 2.5, *p* = .12. Likewise, interactivity did not significantly affect landmark placement, *F*(1, 76) = .04, *p* = .84, and the interaction between interactivity and cognitive load was not reliable, *F*(1, 76) = .02, *p* = .89.

Landmark recall data revealed that cognitive load did not have a significant effect on the number of landmarks forgotten, *F*(1, 76) = .01, *p* = .91. The effect of interactivity and landmark recall was non-significant, *F*(1, 76) = .01, *p* = .91. The interaction between interactivity and cognitive load was also statistically unreliable, *F*(1, 76) = .13, *p* = .72.

Path error data showed that cognitive load significantly affected participants' ability to draw paths of correct length, *F*(1, 76) = 4.09, *p* = .047, *partial* η^2 = .05. Low load participants drew paths with lower error (*M* = 80mm, *SD* = 40mm) than participants in the spatial tapping group (*M* = 103mm, *SD*, = 58mm). Interactivity did not have a significant effect on path length accuracy, *F*(1, 76) = .59, *p* = .44. The interaction between interactivity and cognitive load did not achieve significance *F*(1, 76) < .001, *p* = .99.

Path choice was analysed with a Chi-square analysis. Cognitive load had no effect on the proportion of participants who successfully identified the most efficient path, $\chi^2(1)$ = 0.05, *p* = .65. Interacitivity also did not result in a reliable effect on path choice, $\chi^2(1)$ = 4.69, *p* = .36.

Between-experiment analyses

The following analyses combined the data from Experiments 1 and 5 into a single data set, with the difference between experiments expressed in the "exploration type" variable. Importantly, the only differences between Experiment 1 and 5 were the goal driven exploration instructions and presence of salient paths in Experiment 5. Between subjects ANOVAs were used to test whether map recall differed between Experiments 1 and

5 (i.e., free vs. goal-driven exploration). Interactivity (active, passive), cognitive load (no interference, spatial tapping) and exploration type (free exploration, goal driven exploration) were entered as factors.

All analyses revealed a main effect of cognitive load (all *p*s ≤ .84), with spatial tapping participants outperformed by low load participants. No analyses revealed a main effect of interactivity (all *ps* ≥ .19). The reported results therefore focus on the effect of exploration type (free, goal-driven) and potential interactions.

Pointing Task

The pointing error data revealed a significant effect of exploration type, *F*(1, 152) = 11.46, *p* < .001, *partial* η^2 = .07. Overall, participants demonstrated lower pointing errors following goal-driven exploration (*M* = 43°, *SD* = 22°) in Experiment 5 by comparison with free exploration (*M* = 55°, *SD* = 24°) in Experiment 1. No interactions between interactivity, cognitive load, and exploration type approached significance (all *p*s > .05).

Analysis of response latencies revealed that, overall, the effect of exploration type was not reliable, *F*(1, 152) = .15, *p* = .69. Likewise, no interactions were statistically significant (all *p*s > .05).

Drawing Task

Subjective evaluations showed a reliable effect of exploration type, *F*(1, 152) = 10.17, *p* = .002, *partial* η^2 = .06. The maps of participants who freely explored were rated as less accurate (*M* = 4.80, *SD* = 2.71) than the maps produced by goal-driven participants (*M* = 6.07, *SD* = 2.63). No interactions were reliable (all *p*s > .05)

Landmark placement errors demonstrated no effect of exploration type, *F*(1, 152) = .19, *p* = .66, and all interactions were not statistically reliable (all *p*s > .05)

Analysis of landmark recall data did not show a significant effect of exploration type, *F*(1, 152) = .34, *p* = .56. Likewise, the interactions were not significant (all *p*s > .05)

Discussion

The results from Experiment 5 revealed a pattern of performance which differed from previous experiments. In the pointing task, pointing errors and response latencies were unaffected by the manipulation of interactivity and cognitive load. In the drawing task, subjective ratings and path errors were negativly affected by high visuospatial load while no effect of interactivity was found. In contrast, landmark placement, landmark recall and path choice were unaffected by the manipulation of cognitive load and interactivity. In addition, no measures showed an interaction between interactivity and cogntive load.

These results were not consistent with our hypothesis that high visuospatial load would disadvantage active learners. An active disadvantage under high load had been expected based on the assumption that active learners demand greater visuospatial resources than passive observers, and are hence unable to cope with simultaneous visuospatial interference (Knight & Tlauka, 2017; Sandamas & Foreman, 2014).

It is possible that the goal driven nature of map learning in Experiment 5 reduced cognitive demand in active learners. Assuming this was the case, active subjects may have had the necessary cognitive resources to contend with visuospatial interference and maintain similar map recall as passive observers.The explanation above rests on the notion that goal-driven exploration reduced cognitive demand relative to free exploration. There are two plausible explanations for attenuated cognitive demand in Experiment 5, centred on (1) guided map exploration by path following and (2) the use of mnemonics encouraged by goal-driven exploration. Both explanations apply to some extent to passive observers.

However, the following discussion focuses on active learners because their limied ability to cope with visuospatial demand is critical to the interaction between interactivity and cognitive load.

The first explanation centres on the task requirement in the active group to follow paths in order to discern the most spatially efficient route. In pursuit of this goal, active participants' almost always elected to explore the map by following the three coloured paths. Once a path was fully explored, active participants would typically "restart" exploration by shifting their view back to the initial landmark, then continue by following the course of a different path. Alternatively, some active participants would choose to follow explored paths in reverse (i.e., from east to west) after initial exploration from west to east.

Following paths likely provided active participants with a saliant visual guide to map exploration and a simple means to remain orientated towards their goals (i.e., scrutinising paths and locating landmarks). All landmarks could be located by following paths, so there was no need for participants to deviate from this strategy. It follows that active participants were not required to make difficult decisions about where to explore because the paths always indicated subsequent directions in which to explore. In addition, navigating by paths may have been familiar to active learners, who are more likely to have used paths on maps for this purpose previously (e.g., viewing route guides on digital maps). In contrast, active participants who freely explored (i.e., Experiments 1-4) lacked salient visual guides as to where they should explore. Path following may have alleviated visuospatial demand in Experiment 5, and thus provides a possible explanation for improved map recall in active learners.

The second explanation for a potential attenuated cognitive demand in Experiment 5 concerns the internal structure provided by the three paths. Specifically, the paths featured on both maps remained within approximately the same third of the map for their entire course. On both maps the yellow path travelled the upper (i.e., “north”) third of the map, whereas the blue and red paths either travelled through the centre or lower (i.e., “south”) thirds of the map (see Figures 8 and 9). Given that participants were focused on the paths during exploration, it stands to reason that they may have associated each third of the studied map with its respective path. Participants could have used this a mnemonic strategy, whereby each third of the map was associated with a particular coloured path. This mnemonic could be used to account for improved landmark encoding as landmarks could be clustered into groups (i.e., “chunks”) nested within particular colours. For example, participants who studied map 2 (Figure 9) could group the northern landmarks (i.e., the statue, cinema, and garden) into a chunk associated with the colour yellow. Chunking spatial information has been shown to reduce working memory load (Gobet et al., 2001; Wiener, Ehbauer, & Mallot, 2009; Wiener, Schnee, & Mallot, 2004).

In the current task, grouping landmarks into chunks may have reduced the cognitive effort required to encode landmark locations because participants needed only to remember colour associations. For example, when asked to recall the location of the University the participants may have recalled that the blue path intersected this landmark (see Figure 8). Since the blue path travelled via the centre of the map, the participant will know that the University is also located centrally. To recall the location of the University without path association, the participant would be required to visualise where the University was placed relative to its surrounding landmarks (e.g., “south-east of the church”, “north-west of the hospital” etc.). This example highlights the lower demand required to recall landmarks if chunking is used. Such a strategy would only have been available to participants in Experiment 5 due to the incorporation of paths. In contrast, the maps used in Experiments 1-4 lacked the discrete visual zones necessary to distinguish groups of landmarks.

Previous research supports the notion that humans use features of the environment to reduce cognitive demand while searching for optimal routes. Wiener et al. (2009) conducted several experiments on route choice, focusing on the strategies participants employed to reduce cognitive demand. Participants studied an array of nodes (roughly analogous to landmarks in the current design) situated in a room (Figure 10). Participants were provided with a list of nodes and required to indicate the most spatially efficient circular route between the start location and all listed nodes (i.e., the “travelling salesman problem”). The results demonstrated two distinct strategies employed by participants; (1) the nearest neighbour and (2) clustering. The nearest neighbour strategy illustrated participants’ tendency to follow paths connected to the closest available landmark regardless of whether this route was optimal for traversing the entire path. The clustering strategy was demonstrated by participants who followed a path of landmarks connected in distinguishable groups (i.e., clusters). Following the clustering strategy, participants generally travelled towards the largest cluster of nodes before moving on to complete smaller clusters. Both the nearest neighbour and clustering strategies exemplified participants' attempt to simplify the complexity of path discrimination.

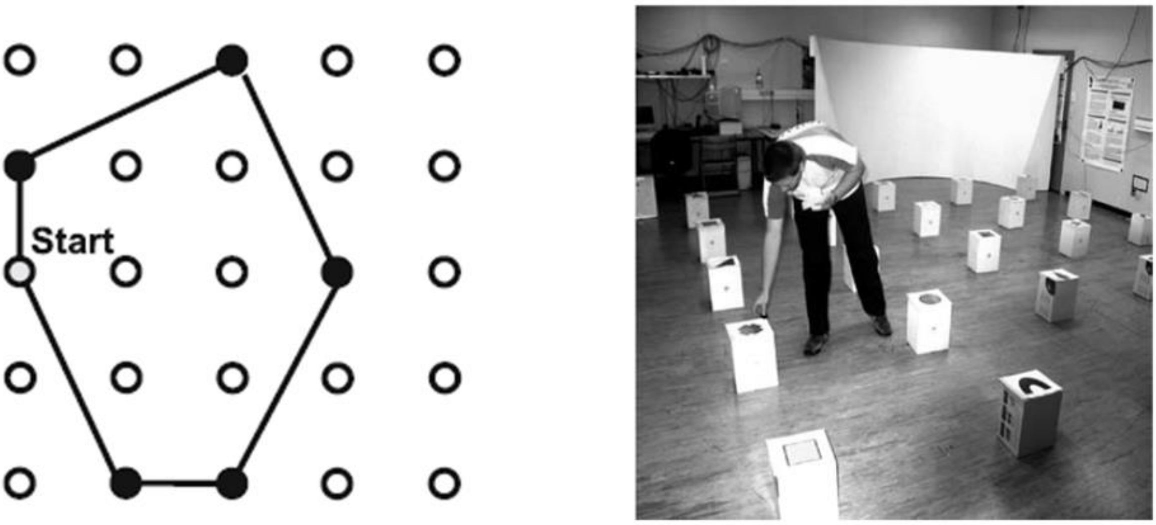

Figure 10. (Right): Nodes studied by participants who were required to make route choices in Wiener et al. (2009). (Left): Diagram of the studied route. The grey circle indicates the starting node, the black circles indicate nodes which must by visited, and the black lines indicate the optimal (i.e., most spatially efficient) circular route.

In a second experiment, nodes were purposefully organised into visually distinct clusters by arranging the groups of nodes into uniform colours (Figure 11). As in the previous experiment, participants were given lists of nodes with which to arrange an optimal path. However, some lists of nodes enabled an optimal path which was consistent with the region clustering strategy whereas other optimal routes were not consistent with clustering. For those lists of nodes inconsistent with clustering, an optimal path could only be found by leaving and then re-entering visually distinct regions. The results showed that participants continued to use a clustering strategy, even for node lists for which this strategy was not appropriate. In other words, participants chose to minimise the number of times they crossed the boundaries of visually distinct regions even when crossing region boundaries more often would result in a superior route.

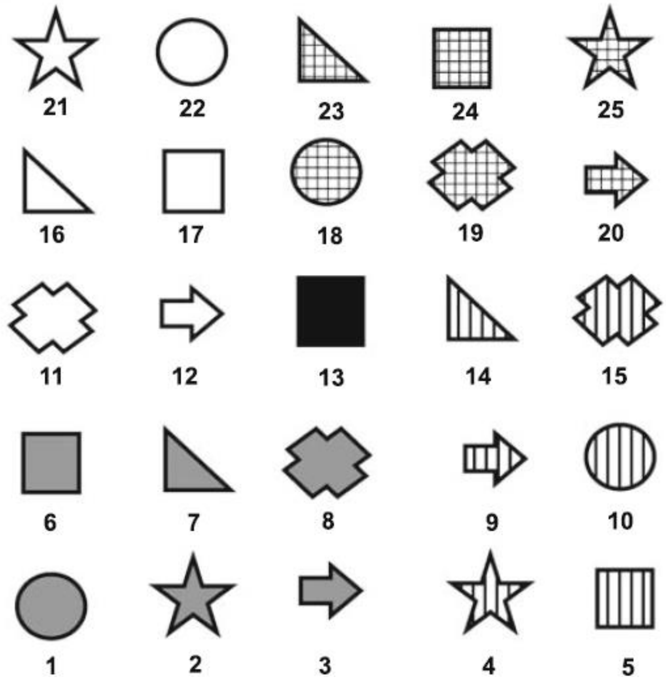

Figure 11. Clustered node regions used in Experiment 2 in Wiener et al. (2009). The nodes were actually differentiated by distinct colours (i.e., black, yellow, red, green, blue) rather than the greyscale contrasts used in this figure.

Spiers and Maquire (2008) also found support for the clustering bias in an applied study on taxi drivers. The results demonstrated that experienced taxi drivers tended to distinguish zones within their city and would plan intermediate routes to reach the border of each zone rather than planning a longer route to the final destination. The findings of Wiener et al. (2009) and Spiers and Maquire demonstrate that when discriminating paths, humans are inclined to use strategies which reduce cognitive load. Associating paths with distinct clustered regions illustrates one such strategy which is relied upon even when more complex paths would produce shorter (albeit, more cognitive demanding) routes.

In the context of the present design, the results of these papers (Spiers & Maquire, 2008; Wiener et al., 2009) support the explanation provided for the unexpected results of Experiment 5. Specifically, it was suggested that goal-driven learning enabled a path-following exploration strategy and encouraged a landmark chunking mnemonic. These explanations are consistent with the suggestion that humans are motivated to used strategies which reduce cognitive effort (Brunye et al., 2010; Christenfeld, 1995; Spiers & Maquire, 2008; Wiener et al., 2009). Goal driven learning may have thus counteracted the active disadvantage observed in Experiment 1 and Knight and Tlauka (2017), as the cognitive demands of map learning may have been alleviated.

A second noteworthy finding in Experiment 5 was that the detrimental effect of high visuospatial load was not consistent across dependent measures. Specifically, high load failed to affect performance in the pointing task and in four measures of the drawing task (i.e., landmark placement errors, landmark recall, path length errors, and path choice). In contrast, performance in Experiment 1 and Knight and Tlauka (2017) showed a more reliable effect of visuospatial interference. The attenuated effect of visuospatial load in Experiment 5 may be explained by reduced cognitive demand, that is, one should expect that the effect of raising cognitive demand should be less pronounced if the baseline difficulty of map learning is decreased.

The analysis comparing map recall between Experiments 1 and 5 support the suggestion that goal driven exploration simplified map learning. These experiments both used a spatial tapping task to raise load. It follows that the only methodological differences between these experiments was the exploration method (free exploration, goal-driven) and the associated presence or absence of salient paths. The analyses of pointing errors and subjective ratings demonstrated that map recall was improved in Experiment 5 in comparison to Experiment 1. These results are consistent with the notion that goal driven exploration encouraged strategies which simplify encoding (i.e., following paths and chunking landmarks).

In summary, the results of Experiment 5 lead to two primary conclusions. First, interactivity does not appear to interact with cognitive load if goal-driven map learning is emphasised. Additionally, the detrimental effect of visuospatial interference appears less reliable in a goal-focused scenario. These findings are likely the result of attenuated cognitive demand, possibly due to the availability of structured exploration and encoding mnemonics.

14. Experiment 6

Experiment 6 was designed to assess the hypothesis that goal-directed exploration attenuates the cognitive demands of map learning and improves map recall in comparison to free exploration. One potential problem was that Experiment 5 used a novel map to counterbalance the visual details of learning. Consequently, the comparison of free and goal-driven exploration (i.e., between Experiments 1 and 5) was confounded by the introduction of a novel map in Experiment 5. Experiment 6 resolved this issue by using both the new and old maps, which were presented to participants in either free exploration or goal-driven scenarios. As in the previous experiments, active and passive participants studied a map either with concurrent spatial tapping or in the absence of interference. The maps studied were either the new map (used in Experiment 5) or the original map (i.e., used in Experiments 1-4) and were presented either with goal driven learning instructions or free exploration instructions (see Figure 12). This design retained the advantage of counterbalancing visual details with multiple maps, while also enabling the manipulation of exploration type (free, goal-driven) in a single experiment.

A further aim of Experiment 6 was to determine whether the active disadvantage under high load was contingent upon free exploration. This notion was evaluated by manipulating interactivity and cognitive load under both free and goal-driven exploration. Given the results of Experiment 5, it was expected that no active disadvantage would be found under goal-driven learning. However, an active disadvantage under high load was expected under free exploration.

A final aim of Experiment 6 was to evaluate the hypothesis that the detrimental effect of visuospatial interference would be greater under free exploration than goal-driven exploration. Goal-driven exploration was expected to diminish the effect of visuospatial interference due to the availability of mnemonics and structured exploration, which may reduce task difficulty in comparison to free exploration.

To summarise, Experiment 6 offered an opportunity to replicate several key findings in the current dissertation: (1) active disadvantage under high load, (2) no effect of interactivity under goal-driven exploration, and (3) attenuated effect of visuospatial load under goal-driven exploration. Assessing the reliability of (1) and (2) was central to verifying the role of interactivity in map learning. Experiment 6 was designed to evaluate (1) and (2) by examining the three-way interaction between interactivity, visuospatial load, and exploration method. Specifically, a high load active disadvantage was expected for participants who freely explored maps, whereas no effect of interactivity was expected for participants who explored with goal-driven instructions. Hypothesis (3) was concerned with a potential mechanism for improved map recall in goal-driven learning (i.e., the attenuation cognitive demand), expressed in the two-way interaction between visuospatial load and exploration method. Specifically, the detrimental effect of high visuospatial load on map recall was expected to be greater for freely explored than for goal-driven maps. Verifying these relationships would make substantial headway in explaining the unreliability of interactivity in the literature (Chrastil & Warren, 2012; Wilson, 1999) by demonstrating the moderating roles of cognitive load and exploration type. The additional complexity imposed by the design of Experiment 6 required a greater number of participants to achieve acceptable statistical power (i.e., 80%). Accordingly, the sample size for Experiment 6 (i.e., *N* = 240) was greater than previous experiments (i.e., *N* = 80), as calculated using the “G*power” software (Faul, Erdfelder, Lang, & Buchner, 2007).

Method

Participants

Two-hundred and forty subjects (48 Males, 192 Females) volunteered to participate in Experiment 6. Participants were reimbursed with course credit or $15.

Materials

The map stimuli used in Experiment 6 were very similar to those used in Experiment 5, albeit four discrete maps were used (Figure 12). Map stimuli included the goal-driven maps used in Experiment 5, and two identical maps presented without paths (i.e., freely explored maps).

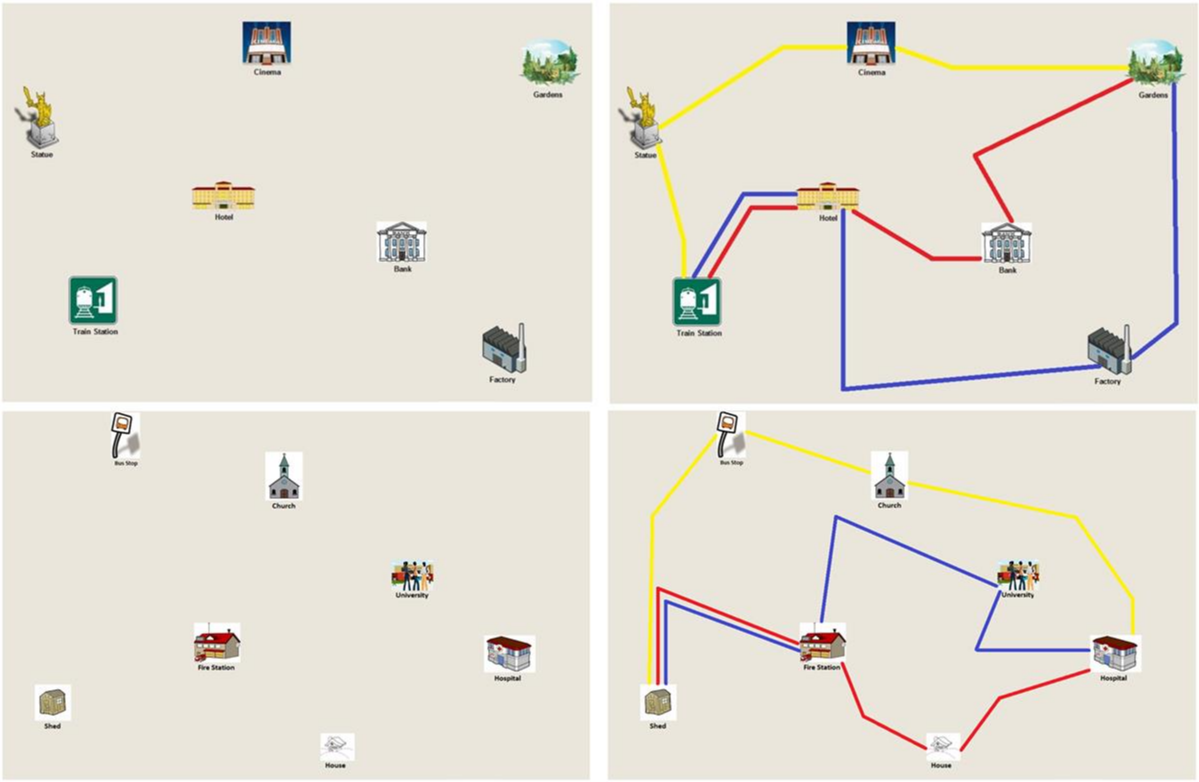

Figure 12. The four maps presented in Experiment 6. The free exploration maps are presented on the left while the goal-driven variants are presented on the right. Each pair of participants only studied a single map.

Procedure

As in the previous experiments, active and passive participants studied a map in the learning phase and then conducted the pointing and drawing tasks. Map exploration was conducted with a spatial tapping interference task (high load) or in the absence of interference (low load). Although four maps were available, each pair of participants only studied a single map such that exploration type (free, goal-driven) was manipulated between subjects. Participants in the free exploration group received the instructions to learn the relative locations of landmarks on the map. Participants in the goal-driven group received additional instructions to determine which of the three paths was the most efficient route between a westerly landmark and an easterly landmark. In the original map (bottom right Figure 12), the evaluated routes were those connecting the Shed and Hospital.

In the new map (top right Figure 12) the evaluated routes were those connecting the Train Station and Gardens.

The testing phase was similar to the previous experiments. All participants completed the pointing task and the drawing task. Only one participant completed the pointing task at a time. Accordingly, whether an active or passive participant completed the pointing task first was counterbalanced. In the drawing task, participants in the free exploration group sketched the map by retaining the correct spatial relationships between landmarks whereas goal-driven participants were also required to include the paths in their drawings.

Results

Data obtained in the pointing task were analysed with mixed analyses of variance (ANOVAs). Interactivity (active, passive), cognitive load (low load, spatial tapping), and exploration type (free, goal driven) were experimentally manipulated between subjects. Alignment (aligned, contra-aligned) was within subjects.

Pointing Task

Pointing errors showed a reliable alignment effect, $F(1, 231) = 128.37$, $p < .001$, *partial* $\eta^2 = .36$. Aligned pointing judgments ($M = 37°$, $SD = 21°$) were more accurate than contra-aligned judgments ($M = 58°$, $SD = 29°$). The main effect of cognitive load was significant, $F(1, 231) = 10.79$, $p < .001$, with low load participants pointing more accurately ($M = 43°$, $SD = 20°$) than participants engaged in spatial tapping ($M = 52°$, $SD = 22°$). The effect of interactivity was not significant, $F(1, 231) = .21$, $p = .65$, nor was the effect of exploration type, $F(1, 231) = .003$, $p = .95$. The expected three-way interaction between interactivity, cognitive load, and exploration type did not approach significance *F*(1, 231) = 3.09, *p* = .81. All two-way interactions were also nonsignificant (*p*s > .19).

Response latency data revealed a significant alignment effect, *F*(1, 231) = 182.55, *p* < .001, *partial* η^2 = .44. Aligned questions were answered faster (*M* = 5.1seconds, *SD* = 2.1seconds) than contra aligned questions (*M* = 7.5, *SD* = 3.4). Both cognitive load, *F*(1, 232) = .26, *p* = .61, and interactivity, *F*(1, 231) = .001, *p* = .70, did not result in significant effects. The effect of exploration type was also nonsignificant, *F*(1, 231) = .15, *p* = .70. The predicted three-way interaction was non-significant *F*(1, 231) = 1.30, *p* = .25, as were all two-way interactions (*p*s > .05)

Drawing Task

The drawing task data was tested with between subjects ANOVAs. Interactivity (active, passive), cognitive load (low load, spatial tapping), and exploration type (free, goal driven) were entered as factors. Separate ANOVAs were run for subjective ratings, landmark placement errors, landmark recall and path error. Chi-square analyses were used to analyse route choice data. Measures specific to goal-driven maps (i.e., path error and route choice) were only possible to analyse for goal-driven maps, as freely explored maps did not contain paths (Figure 12).

Subjective ratings were obtained from two judges who were blind to the allocation of participants to experimental groups. The judges' ratings were strongly correlated, *r*(238) = .80, *p* < .001, and averaged into a single variable. Cognitive load demonstrated a significant effect on subjective ratings, *F*(1, 231) = 34.47, *p* < .001, *partial* η^2 = .13. The maps of participants in the spatial tapping group (*M* = 3.78, *SD* = 2.24) were rated as less accurate than those of the low load group (*M* = 5.54, *SD* = 2.40). Interactivity did not lead to a statistically consistent effect, *F*(1, 231) = .50, *p* = .48. However, exploration method significantly affected map ratings, *F*(1, 231) = .4.17, *p* = .04, *partial* η^2 = .02. On average, maps of goal-driven subjects (*M* = 4.35, *SD* = 2.44) were rated as less accurate than maps produced by subjects in the free exploration group (*M* = 4.96, *SD* = 2.48). The interaction between interactivity, cognitive load, and exploration type were not significant *F*(1, 231) = .005 *p* = .94., nor were any two-way interactions (*p*s > .05)

The analysis of landmark placement data showed a significant cognitive load effect, *F*(1, 231) = 32.68, *p* < .001, *partial* η^2 = .12. Low load participants drew more accurate maps (*M* = 44mm, *SD* = 19mm) than participants who were asked to perform a spatial tapping task (*M* = 62mm, *SD* = 28mm). Neither interactivity, *F*(1, 231) = .40, *p* = .53, nor exploration method, *F*(1, 231) = .2.75, *p* = .10, significantly affected landmark placement. The expected three-way interaction was not reliable, *F*(1, 231) = 1.47, *p* = .23. Likewise, all two-way interactions were not significant (*p*s > .05)

The landmark recall data revealed a marginal effect of cognitive load on the number of landmarks forgotten, *F*(1, 231) = 3.76, *p* = .054, *partial* η^2 = .02. Low load participants tended to forget fewer landmarks (*M* = .4, *SD* = .8) by comparison with participants in the spatial tapping group (*M* = .64 *SD* = .8). Interactivity was not significant, *F*(1, 231) = 2.65, *p* = .11. Likewise, participants' exploration method did not affect landmark recall, *F*(1, 231) = 1.74, *p* = .19. The three-way interaction between interactivity, cognitive load, and exploration type was not significant, *F*(1, 231) = .054, *p* = .82, nor were the two-way interactions (*p*s > .05).

Among the goal-driven group, data for path drawing error demonstrated that high load detrimentally affected participants' ability to draw paths of correct length, *F*(1, 116) = 4.90, *p* = .03, *partial* η^2 = .04. Low load participants drew paths with lower mean error (*M* = 89mm, *SD* = 48mm) compared to participants in the spatial tapping group (*M* = 109mm, *SD* = 50mm). Interactivity did not significantly affect path length accuracy, *F*(1, 116) = 1.69, *p* =

.20. The interaction between cognitive load and interactivity did not approach significance, *F*(1, 116) .026, $p = .87$.

Path choice was analysed with a Chi-square analysis. This analysis evaluated the likelihood of participants to successfully identify the most efficient path. Interacitivity failed to produce a reliable effect on path choice accuracy, $\chi^2(1) = .30$, $p = .58$. Likewise, cognitive load did not affect participants' path choice, $\chi^2(1) = .30$, $p = .58$.

Discussion

Overall, the results from Experiment 6 were not consistent with expectations. Critically, no measures detected the expected three-way interaction between interactivity, cognitive load and exploration type. In the pointing task, high visuospatial load impaired pointing judgments, but did not affect response times. A detrimental effect of high load was also found in the drawing task, i.e., in subjective ratings, landmark placement, and landmark recall. For those participants who studied goal-driven maps, high load was detrimental to drawing paths of accurate length. In contrast, participants' ability to correctly identify the most efficient path was not affected by load. Exploration type only revealed a significant effect for subjective judgements, in which the maps drawn by participants in the free exploration group were rated as more accurate than those drawn by the goal-driven group. No other measures revealed an effect of exploration method.

A critical finding in Experiment 6 was the lack of three-way interaction between interactivity, cognitive load, and exploration type. It had been expected that among free exploration participants, active learners would be disadvantaged in the high visuospatial load group. For goal-driven participants, it was expected that no effect of interactivity would be found. These predictions were based on the assumption that goal-driven exploration improves map learning, which may attenuate the active disadvantage in the high load group. This notion was not supported by the results of Experiment 6, as interactivity had no effect on map learning regardless of participants' exploration method. The current results therefore failed to replicate the high load active disadvantage observed in Experiment 1. Given this finding, it may be concluded that activity is not reliably detrimental to map learning.

The finding that exploration method does not moderate the effect of interactivity is consistent with two experiments by Wilson et al. (1997). Exploration method was manipulated between experiments by asking active and passive subjects to freely explore a virtual environment (Experiment 1) or locate objects initially hidden from view (Experiment 2). The results showed that interactivity had no effect on survey learning regardless of subjects' exploration method (i.e., free, goal-driven). The current findings extend this conclusion to the map learning domain such that using maps in a goal-driven manner does not alter the effect of interactivity.

In contrast to interactivity, the detrimental effect of visuospatial load in Experiment 6 mirrored the findings from Experiment 1 and those reported by Knight and Tlauka (2017). Impaired map recall under spatial tapping lends further support to the notion that survey acquisition from maps is highly reliant on the visuospatial sketchpad (Coluccia, 2005). Specifically, visuospatial processing is likely required to encode the relative locations of landmarks and the length of paths depicted on a map (see Coluccia, 2007). It is noteworthy that visuospatial interference did not affect participants' ability to detect the most efficient path, a result which was also found in Experiment 5. A plausible explanation is that the decision criteria involved in path choice are processed in the central executive (Baddeley, 1983; Gathercole et al., 2004), and were hence less affected by visuospatial interference.

In Experiment 6 visuospatial load and exploration type did not interact. This finding runs contrary to previous interpretation of the data in Experiment 5. Specifically, the results of Experiment 5 suggested that the detrimental effect of high load was reduced by goal-driven exploration. In addition, the between-experiment analyses showed that map recall in Experiment 5 was superior to that of participants in Experiment 1. The only difference between these experiments was the presence of goal-focused instructions and salient paths in Experiment 5 rather than the free exploration emphasised in Experiment 1. It was therefore suggested that goal-driven exploration simplifies map learning and attenuates the detrimental effect of visuospatial interference compared to free exploration. The results of Experiment 6 did not support this conclusion as the effect of visuospatial load did not differ between free and goal-driven learning groups.

The reliable effect of spatial tapping in Experiment 6 implies that map learning is highly reliant on visuospatial working memory regardless of the manner in which the map is explored. A related finding of interest was that exploration method generally failed to produce main effects on map recall, reinforcing the conclusion that goal-driven exploration does not attenuate the cognitive demands of map learning. One exception was observed in the subjective ratings data, which showed superior evaluations for free exploration drawings. A likely explanation is that the map raters were biased to negatively evaluate goal-driven maps because these maps contained a greater amount of spatial information. Specifically, goal-driven participants were required to depict paths and landmarks in their drawings. In contrast, participants who freely explored were only required to depict landmarks (not paths). The greater quantity of spatial information required by goal-driven maps may have negatively affected subjective ratings, as there were more opportunities for participants to display spatial inaccuracies in their depiction of paths. It follows that this result is more likely to be a feature of measurement than it is to be attributable to participants' exploration method. This conclusion is supported by the fact that no other measures detected an effect of exploration method.

In sum, survey learning from maps appears to be unaffected by exploration method, possibly because the visuospatial demands of free and goal driven map learning are similar. This result is in contrast with work by Taylor et al. (1999) (p. 18), which suggested that route-centric goals improve spatial memory for routes presented on a map. The divergent findings may be the result of different map learning instructions. In the current work, participants were asked to remember the spatial layout of the map (i.e. survey information) and evaluate the shortest path between two points (i.e., goal-focused learning). In contrast, Taylor et al. manipulated map learning instructions such that participants either focused on learning survey information <u>or</u> engaged in goal-focused route learning. Pursuing both survey and goal-centric objectives may have been cognitively demanding and hence negated the potential benefit of goal-driven map learning.

The finding that exploration method did not affect map recall provides a plausible explanation for the lack of active disadvantage in the free exploration group. This is so because active disadvantage in spatial learning appears to be associated with high cognitive load (Chrastil & Warren, 2012; Knight & Tlauka, 2017; Sandamas & Foreman, 2014). It follows that activity is more likely to be detrimental to map learning if the learning task itself is cognitively demanding. There appears to be no difference between the cognitive demands of free and goal-driven map learning, so there is little reason to expect that active subjects should be detrimentally affected by free-exploration.

Experiment 6 provides valuable information regarding the role of goal-driven exploration in map learning. However, an important question remains unanswered regarding the presence of paths in maps and their effect on learning independent of goal-driven learning. Specifically, it is possible that including salient paths in maps is beneficial to learning because paths may provide participants with a mnemonic device (i.e., chunking) and a guide to map exploration (i.e., path following). However, these advantages may be counteracted by the additional cognitive load required to evaluate the spatial efficiency of paths. In the current design, path presence and path evaluation were confounded such that participants who learned maps with paths were always required to evaluate the spatial efficiency of paths. Separating these variables (i.e., path presence/path evaluation) is outside the scope of the current dissertation, but is an interesting question for future research.

In summary, the results of Experiment 6 offer important qualifications to a number of issues raised in the previous experiments. First, the active disadvantage under high load was not a consistent finding. In contrast, high visuospatial load consistently impairs map recall. Finally, participants' exploration method does not affect performance, nor does exploration method interact with interactivity or visuospatial load. These findings suggest that our ability to obtain information from maps is contingent upon the availability of visuospatial working memory, whereas the active disadvantage may be less reliable than initially hypothesized.

15. General Discussion

The aim of this dissertation was to investigate interactivity in map learning and examine the notion that cognitive load could provide an explanation for why active learners often under-perform in tests of interactivity. Specifically, it was suggested that activity demands greater cognitive resources than passive observation and therefore activity may be detrimental to spatial learning if cognitive load is high. The following paragraphs summarise how each experiment contributed to this research objective and highlight the primary conclusions.

Experiment 1 found support for the primary hypothesis, as activity was detrimental to map learning if participants were engaged in visuospatial interference. In contrast, interactivity had no effect if the map was studied in the absence of interference. This result replicated the findings of an earlier experiment (Knight & Tlauka, 2017) in which the same pattern of active disadvantage was found across a number of dependent measures. Experiment 1 also revealed that map learning was consistently impaired by simultaneous visuo-spatial interference, suggesting that high load is detrimental to map learning. Subsequent experiments replicated this cognitive load effect, regardless of the modality of load (i.e., visuospatial, verbal, central executive) or exploration method (i.e., free, goal-driven).

Experiments 2, 3 and 4 were intended to distinguish whether the active disadvantage was modality dependent. Specifically, it was investigated whether high verbal and central executive load would also produce an active disadvantage, similar to that produced by high visuospatial load. The experimental design was modified to address this question such that participants explored the map while conducting simultaneous verbal

(Experiments 2 and 3) or central executive (Experiment 4) interference tasks. Experiments 2-4 did not reveal an effect of interactivity, suggesting that the active disadvantage was contingent upon high visuospatial load and was not the result of generic cognitive load. Along with the results of Experiment 1, these findings imply that activity demands greater visuospatial resources than passive observation. In contrast, verbal and executive resources appeared to be in equal demand by active and passive learners.

Experiment 5 investigated whether the active disadvantage observed in Experiment 1 would be retained if participants were given a goal-driven task while exploring a map. The rationale was that in real life, maps are generally used to navigate toward a goal in an unfamiliar environment (e.g., locating a train station in an unfamiliar city). Participants studied one of two maps similar to that used in Experiments 1-4, albeit three distinct paths were incorporated. Participants received the standard instructions to learn the spatial layout of the map as well as additional instructions to determine which of the three paths was the most efficient route between two landmarks. The results revealed that interactivity had no effect on map recall regardless of participants' cognitive load (i.e., low load, visuospatial interference).

Given that the only methodological difference between Experiments 1 and 5 was participants' exploration method, the results were consistent with the hypothesis that goal driven navigation was not conducive to the detection of an active disadvantage. It was suggested that goal-driven maps encourage structured exploration and mnemonic strategies and therefore reduce cognitive demand. If goal-driven exploration improved map learning, this would explain the ability of active learners to cope with high visuospatial demand in Experiment 5 while coping less effectively in Experiment 1.

Experiment 6 was designed to evaluate this interpretation while also trying to replicate the active disadvantage found in Experiment 1. Exploration method was experimentally manipulated such that participants either freely explored maps or were provided a goal-driven test. For subjects who freely explored, it was expected that active learners would be detrimentally affected by high visuospatial load. In contrast, goal driven participants were not expected to be influenced by interactivity. The results were not consistent with this hypothesis. Regardless of exploration method activity did not impair participants' map learning. These findings imply that an active disadvantage under high load is not reliant upon free exploration, but rather that this effect is less reliable than initially assumed or affected by as yet undetermined variables.

It should be acknowledged that there is an alternative explanation for the different patterns of interference effects observed in Experiment 1, relative to Experiments 2-4. It is possible that the verbal and central executive interference tasks employed in Experiments 2-4 were simply more difficult than the spatial tapping task used in Experiment 1. Greater generic (i.e., domain general) difficulty could explain why active and passive learners were similarly affected by interference in Experiments 2-4, but not in Experiment 1. However, this conclusion hinges on the unintuitive assumption that articulatory suppression (i.e., Experiment 3) is more difficult that spatial tapping (i.e., Experiment 1). This assumption is unintuitive due to the simplicity of repeating the word "the", in comparison to the relative complexity of maintaining temporal and spatial accuracy in spatial tapping. As a result, the task difficulty explanation does not provide a robust account of the interference effects in Experiments 1-4.

Similarly, it is possible that spatial tapping in Experiment 6 incurred greater difficulty than Experiment 2, and hence negatively affected performance in active and passive learners. This explanation does not suggest that active disadvantage is contingent upon high visuospatial load, instead suggesting that learners are negatively affected by difficult interference tasks (e.g., spatial tapping, backwards counting), regardless of task modality. However, this explanation does not take into account the finding that Experiment 1 used an identical spatial tapping task to that used in Experiment 6, and produced an active disadvantage. In addition, the active disadvantage was observed in Knight and Tlauka (2017), which used spatial tapping with hands. Given that only high visuospatial load has been shown to produce an active disadvantage, I suggest that modality specific demands provide a better explanation for the results of Experiments 2 and 6 than domain-general task difficulty.

15.1 Implications for interactivity

Experiment 1 of the current thesis and Knight and Tlauka (2017) suggested that activity was detrimental to map leaning if visuospatial load is high. However, Experiment 6 of the present series of experiments failed to replicate this effect. Although the active disadvantage appears inconsistent, our results demonstrated a consistent pattern at-odds with the existing interactivity literature. Specifically, none of the current experiments revealed an active advantage regardless of the modality of cognitive load imposed or participants' exploration method. This finding runs contrary to the notion that activity reinforces encoding and improves spatial learning (Chrastil & Warren, 2012; Wilson, 1999).

It is possible that maintaining visual attention is sufficient to encode spatial information from maps. In the current experiments, active and passive participants had an almost identical view of the map, with the only difference being sitting position at the table (i.e., left or right), which was counterbalanced. Active control did not obscure active participants’ view of the map, nor did passive observation reduce the quality of viewing in passive learners. Given that interactivity did not reliably affect map learning, it is suggested that map learning is reliant on visual attention rather than learners’ degree of interactivity. In other fields (e.g., driving simulation studies) it may be more difficult to equate visual attention in active and passive learners because active learners’ attention may be drawn to their control interface (Sandamas and Foreman, 2014). Likewise, passive observers may become disinterested in lengthy spatial learning tasks due to lack of interaction or stimulation, which could result in drifting visual attention and impaired spatial recall. In contrast, the current map learning task was only 2.5 minutes in duration, so passive participants were able maintain attention without difficulty.

The present results highlight the importance of controlling visual attention in studies of interactivity, as interactivity appears to have no reliable effect on survey learning from maps, provided active and passive learners have a clear view. The notion that visual attention is sufficient to encode spatial information was also supported by Wilson (1999) (see section 5.1). Wilson asked active participants to explore a virtual environment presented on a monitor while passive participants simply observed the same monitor. Accordingly, participants’ visual experience was the same regardless of their level of interactivity. The results showed that survey memory was unaffected by interactivity, suggesting that interactivity may have no effect on survey learning if subjects’ visual experience is controlled.

A different explanation for the inconsistent results of interactivity by Sandamas and Foreman (2007, 2014) and Sandamas et al. (2009) also deserves discussion. In a series of experiments, Sandamas et al. demonstrated that active exploration of a virtual environment was only beneficial if active learners were given the opportunity to become familiar with a control interface. Without the opportunity to become familiar, active participants showed similar or impaired spatial learning in comparison to passive controls. These findings suggested that activity is cognitively demanding, to the extent that novel control interfaces may overload active participants. It was hence inferred that any benefit of activity is contingent upon interface familiarity in active learners. In the current map learning design, active learners were not provided the opportunity to practice exploration before the study phase began. It could be suggested that active learners would have benefitted from map exploration training, which could explain the inconsistent results in the current design. However, there are notable issues with applying the conclusions of Sandamas and Foreman and Sandamas et al. to the current results.

Critically, the control scheme of exploring the map in the current design was simple in comparison to the interfaces employed by Sandamas and Foreman (2007, 2014) and Sandamas et al. (2009). To explore the virtual environments in their experiments participants were required to manipulate either a joystick or keyboard. These input devices were used to adjust the displacement and view available to active subjects. In the current design, participants controlled exploration by physically moving a sheet of cardboard to explore the map by the central hole. Although the current exploration method was presumably a novel experience, it was unlikely to be cognitively demanding to the same extent as actively controlling a joystick or keyboard.

One reason for the lower demand in the current design is that the map learning task focused participants’ visual attention on the control interface (i.e., the sheet of cardboard). Directly observing the sheet of cardboard enabled participants to visually confirm the precision of their desired movements. In contrast, participants’ visual attention in Sandamas’ et al. experiments was split between an input device (i.e., joystick or keyboard) and the monitor displaying the virtual environment. Shifting attention between verifying correct interface usage and the display may have increased central executive demand (Baddeley, 1983; Gathercole et al., 2004) by comparison with the present design. In addition, moving the sheet of cardboard about the map was likely more intuitive than controlling exploration by a joystick or keyboard. If the active subject in the current design wished to explore the left side of the map, he needed only to physically shift the cardboard to the left. In contrast, participants required to use a joystick or keyboard may have needed to consciously deliberate how to use the given input device to adjust their view of the virtual environment in the desired manner. Given that map exploration was simple and intuitive, it seems unlikely that training was a significant factor in the current experiments. Nevertheless, future work could investigate this hypothesis empirically by comparing the map learning of subjects who receive or do not receive training.

In Experiment 6, the high load active disadvantage could not be replicated. However, the active disadvantage under high load is still worth considering, as the effect was initially found in Knight and Tlauka (2017) and subsequently replicated in Experiment 1 of this thesis. Taken the present results and those of Knight and Tlauka together, it is suggested that activity may demand greater visuospatial resources than passive observation (Sandamas & Foreman, 2007; 2014; Sandamas et al., 2009), which can result in an active disadvantage if visuospatial resources are in high demand. In contrast, active and passive learning appears to be equally impaired by high verbal and central executive load. These results make some headway in explaining inconsistencies in tests of interactivity, as high visuospatial load does not appear conducive to the typically expected active advantage (Chrastil & Warren, 2012; Wilson, 1999).

Following the reasoning above, it is possible that studies which use experimental tasks placing high load on the visuospatial sketchpad may be less likely to detect an active advantage. Researchers typically endeavour to design cognitively demanding tasks to avoid ceiling effects. Although avoiding ceiling effects is desirable, the use of such demanding tasks in visuospatial research may detrimentally affect active learners, which could explain why expected active advantages often fail to occur (e.g., Wan et al., 2010; Wilson, 1999; Wilson & Péruch, 2002). The notion that activity is more demanding than passive observation is has been explored previously (Chrastil & Warren, 2012; Sandamas & Foreman, 2007, 2014; Sandamas et al., 2009). However, the current experiments (in conjunction with Knight & Tlauka, 2017) offer the first example of active disadvantage under high load in a map learning task. Additionally, the present findings are the first to demonstrate that visuospatial load may impair active learners while verbal and executive load impairs learning regardless of subjects' level of interactivity.

Inconsistencies in interactivity effects have been observed in previous studies. For example, Chrastil and Warren (2013) investigated the influence of interactivity on survey learning following exploration of a virtual hedge maze (see section 5.1). Participants explored the hedge maze by walking, being pushed in a wheel chair, or by viewing a video of exploration. Within these groups participants either made decisions about where to explore, or were guided by the experimenter. The results showed that walking through the maze was beneficial compared to the wheelchair and video viewing groups. In contrast, making exploratory decisions failed to improve subjects' survey learning. These findings were interpreted as evidence that survey learning benefits from visuospatial information associated with walking (i.e., efferent & proprioceptive information). In contrast, vestibular information alone (i.e., the wheelchair group) does not aid learning, nor does making decisions. This investigation provides an example of a limited interactivity effect. Similar to the current dissertation, most comparisons in Chrastil and Warren’s experiment revealed no difference between active and passive groups (i.e., no effect of decision making or wheel chair control). Only a single comparison (i.e., between walking and video viewing) revealed a beneficial effect of activity.

In a second hedge maze experiment by the same authors (Chrastil & Warren, 2015) the focus shifted to graph knowledge, in contrast to the previous emphasis on survey knowledge. Graph knowledge was defined as an intermediary stage of learning between route and survey knowledge. To constitute graph knowledge, it was argued that a learner must demonstrate knowledge of the interconnected paths within an environment rather than simple place-action associations on a single path (i.e., route knowledge). Although graph and survey knowledge are similar, individuals with only graph knowledge lack Euclidian information about distances and directions which enable inference of novel shortcuts. As in their previous experiment, participants either explored the virtual maze by walking or by viewing a video (the wheel chair group was omitted).

Following the virtual learning task, graph knowledge was evaluated by having participants locate a studied test object within the hedge maze. However, spatial learning was measured differently, reflecting the change in the authors’ focus on graph (rather than survey) knowledge. Specifically, in certain trials the optimal path to the test object was blocked such that participants needed to use their knowledge of the interconnected routes in the maze to change their course (i.e., rely on graph rather than route knowledge). The results showed a different pattern of performance relative to their previous experiment (Chrastil & Warren, 2013). No effect of exploration mode was found, as graph knowledge did not differ between subjects who walked and subjects who viewed a video of exploration. However, a significant interaction was found between decision making and mode of exploration. For the walking group, decision making improved graph knowledge, whereas in the video viewing group decision making had no effect. The authors suggested that decision making is a beneficial component of activity only if it is paired with the visuospatial information acquired from walking. Taken together with the results of Chrastil and Warren (2013), the authors concluded that graph and survey knowledge benefit from distinct components of activity. Specifically, survey learning appears to benefit from walking, but is not affected by decision making. In contrast, graph knowledge is not affected by walking alone, but does benefit from decision making in combination with walking.

The results of Chrastil and Warren (2013, 2015) offer an example of inconsistent effects of interactivity in related experiments. Although the authors' findings can be interpreted as demonstrating discrete benefits of activity for survey and graph learning, there is an alternative explanation. Specifically, it could also be argued that the effect of interactivity on graph and survey learning should be consistent. Given that forms of knowledge pertain to large-scale cognitive representations of environments, it may not be expected that activity should differentially affect graph and survey learning. Their results are also consistent with the notion that the divergent patterns of performance across these experiments are attributable to the unreliability of interactivity effects in general. The findings of the present dissertation are aligned with this interpretation, as the results revealed that the effects of interactivity were not consistent across experiments. The discussed work by Chrastil and Warren (2013, 2015) exemplifies how the present results can be used to aid interpretation of other effects in interactivity research. In particular, the present findings suggest that isolated or limited effects of interactivity should be interpreted with care, as they may not generalise across different experimental situations.

The inconsistent active advantage observed raises an important question. Why is activity assumed to be beneficial to spatial learning? One explanation is that cognitive activity is an important component for the improvement of learning and memory retention in other domains (Bonwell & Eison, 1991; Prince, 2004). For example, when preparing for exams students are generally advised to "actively" study their assessment material to improve future recall. In contrast, "passively" reading assessment material is not recommended. The success of general active learning strategies may be assumed to carry over to the domain of spatial memory. The current findings suggest that the expectation for active advantage should not apply to map learning. In fact, it may be sensible for researchers to expect no effect of active engagement, particularly if the task demands high visuospatial load.

A final discussion of interest with regards to interactivity is the application of the current findings in applied scenarios. The present findings imply that programs which aim to improve map learning (e.g., orienteering, military navigation) may benefit equally from passive and active approaches. This similar benefit is important to acknowledge because passive programs may be automatically excluded due to the assumption that active learning is superior. It is worth considering passive programs (e.g., observing a teacher, see below), as they may be cheaper or less labour intensive than those which require active control. For example, it is possible that passive observation of an instructor teaching map exploration and describing environment details could provide a similar benefit to having students manipulate maps and explore environments themselves (i.e., an active approach). The passive instructional approach may be more cost and time efficient, and could provide a similar benefit in comparison the more intensive active approach. The current results support the use of active and passive map learning strategies and suggest that passive approaches should not be overlooked.

In summary, there appears to be no consistent picture with respect to potential differences between the quality of knowledge obtained from active and passive map learning. Although Experiment 1 demonstrated that activity may be detrimental if visuospatial load is high, this pattern was not replicated in Experiment 6. These results support the findings of previous researchers with stimuli other than maps, which have also shown that the effect of interactivity is difficult to isolate in an experimental setting (Chrastil & Warren, 2012; Wilson, 1999). The finding that activity failed to improve map learning is not in agreement with the notion that activity is beneficial to a wide range of spatial learning scenarios. These include applied scenarios, in which the current results may be helpful in identifying the value of passive map learning programs.

15.2 Implications for working memory

Cognitive load produced a reliable pattern across experiments, as map learning was detrimentally affected by high visuospatial, verbal, and central executive interference. This finding has several important and novel implications for the working memory paradigm in the map learning domain. For instance, Experiments 2, 3 and 4 advance our understanding by demonstrating that high verbal and central executive load impair survey acquisition from maps. Furthermore, the detrimental effect of high load appears to be consistent across egocentric (i.e., pointing) and allocentric (i.e., drawing) tasks, suggesting that different tasks are negatively affected.

Raising verbal and executive load significantly diminished participants’ ability to recall the map, suggesting that map learning relies on resources from the phonological loop and central executive. This finding is divergent from the traditional notion that map learning is primarily a visuospatial task (Bosco et al., 2004; Coluccia, 2005; Coluccia et al., 2007). A possible explanation for the verbal and executive contribution may be found in the sequential exploration design of the map learning task. In the current experiments, participants sequentially explored the map by viewing it through a small hole in the cardboard, which was moved to gradually expose different areas. In contrast, traditional paper maps are typically presented in a simultaneous format, in which all information is immediately available to the learner (e.g., road map books). Most previous tests of map learning have used simultaneous viewing designs (e.g., Coluccia, 2006; Brunyé et al., 2010; Moeser, 1988; Thorndyke & Hayes-Roth, 1982), which may not rely on verbal or executive resources to the same extent as sequential map learning.

Let us consider the role of verbal and central executive memory in processing sequential information. In the verbal domain, research by Pazzaglia and Cornoldi (1999) provides an example of spatial-sequential tasks demanding resources from the phonological loop. In their Experiment 1, participants were required to read several different types of descriptions (i.e., abstract, visual, spatial-sequential, or spatial-simultaneous) and remember as many details of these descriptions as possible. The results showed that backwards counting (i.e., verbal interference) reduced recall of spatial-sequential descriptions, but not spatial-simultaneous descriptions. This finding suggests that verbal memory is used in processing sequential, but not simultaneous, spatial information.

Experiment 3 of Pazzaglia & Cornoldi (1999) reinforced this conclusion. Participants were verbally presented with different types of descriptions of several environments and asked to remember as many details as possible. The experimenter provided descriptions focused on route instructions or descriptions focused on visual details of landmarks. Route descriptions emphasised instructions connecting landmarks along a path (e.g., “follow the road towards the zoo, then turn left”). In contrast, visual descriptions focused on properties such as the shape or size of landmarks and the distance between them. Route descriptions engender verbal rehearsal strategies and are therefore more reliant on the phonological loop than visual descriptions (Chrastil & Warren, 2012; Kelly et al., 2015; Rudkin et al., 2007).

While listening to the descriptions participants conducted a modality-specific interference task (i.e., a spatial-sequential, spatial-simultaneous, or a visual interference task). The interference tasks involved presenting participants with several arrays of hand-drawn figures (e.g., a duck, scissors, a pipe) and asking participants to indicate if a figure array differed from a previously presented array (see Figure 13). The modality of this interference task was manipulated by altering the manner in which differences between arrays were presented. In the visual interference task the arrays could present a different hand-drawn figure (e.g., a duck instead of scissors), thus requiring participants to detect a visual modification. In the spatial-simultaneous interference task the arrays could differ by presenting figures in a new spatial arrangement (Figure 13). In the spatial-sequential interference task the individual figures were presented gradually within each array (1 figure per 400ms), and the sequence of figure presentation could differ between arrays. Spatial memory for descriptions was measured by asking participants to recall the environment described in as much detail as possible and recording the number of correct items of information provided by the participant.

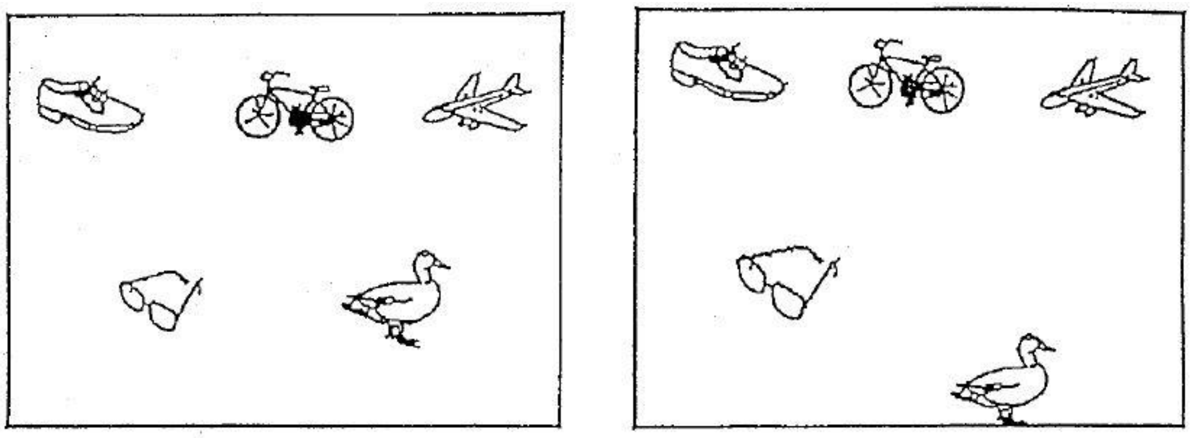

Figure 13: Example of arrays presented in the spatial-simultaneous task in Pazzaglia and Cornoldi (1999). The figures within each array were identical, however the spatial location of figures within the array could differ.

The results demonstrated that spatial-sequential interference impaired memory for route descriptions to a significantly greater extent than spatial-simultaneous or visual interference. This finding suggests that verbal route descriptions rely on sequential processing (Pazzaglia & Cornoldi, 1999; Gathercole & Baddeley, 1999). In contrast, sequential and simultaneous interference equally impaired memory for descriptions which focused on visual (rather than route) aspects of the environment. The results of Pazzaglia and Cornoldi therefore reinforce the explanation provided for the current results that verbal resources contribute to map learning by facilitating the acquisition of sequentially presented information.

In the map learning domain, the contribution of verbal memory in sequential tasks may help explain the previous inconsistency in map learning highlighted by Coluccia et al. (2007) and Garden et al. (2002). Recall that Garden et al. (2002) found that verbal interference impaired map learning whereas Coluccia et al. (2007) showed that map learning was not affected by verbal load. Importantly, in Garden's et al. experiment participants viewed the map sequentially by observing discrete snapshots which, when taken together, portrayed a map. Sequential viewing may have encouraged verbal encoding strategies including subvocalisation, in which the subject uses linguistic mental rehearsal of spatial relationships (e.g., “the Shed is west of the Hospital”). Verbal interference may have inhibited subvocalisation, thus impairing map recall. In contrast, in Coluccia’s et al. experiment participants viewed the entire map at once (i.e., simultaneous viewing), which may have encouraged visuospatial encoding strategies (e.g., studying spatial relationships) which were not affected by verbal interference. Visual strategies may be more effective at encoding simultaneously presented maps because the absolute locations of landmarks and other visual information is immediately available. Simultaneous visuospatial information, when presented on a map, may be directly encoded into a “bird’s eye view” survey representation (Montello, 2002). Such direct encoding of simultaneous map information may not rely on verbal encoding strategies. The present results hence provide a potential explanation for the inconsistency in the role of the phonological loop in map learning, as the simultaneous/sequential difference in viewing may explain why a verbal contribution was found by Garden et al., but not by Coluccia et al.

With respect to the central executive an experiment by Rudkin et al. (2007) suggested that sequential tasks require greater executive load than simultaneous tasks. As described previously (see section 7.4), participants conducted simultaneous and sequential primary tasks while also performing an executive interference task. Specifically, participants completed a Matrix Pattern task (simultaneous) and Corsi Blocks task (sequential). The difficulty of both primary tasks was gradually increased by raising the number of items of visuospatial information to be recalled (i.e., a larger matrix pattern, or more blocks presented). Performance was measured by identifying the point at which participants could no longer complete the matrix pattern or Corsi block sequence. These primary tasks were performed in parallel with executive interference, which involved subjects verbally producing numbers from 1-10 at random. Random number generation diminished performance to a greater extent in sequential than in simultaneous visuospatial learning tasks, leading the authors to conclude that sequential tasks exert greater executive demand. The findings of Rudkin et al. are therefore consistent with the notion that sequential map learning places executive resources in high demand.

A plausible explanation for the contribution of the central executive in sequential tasks is in shifting attention and integrating novel information into an existing memory framework (Gathercole et al., 2004; Baddeley, 1983). By their nature, sequential tasks emphasise the gradual acquisition of new information, which requires shifts of attention toward new stimuli. In the context of map learning, executive resources may be involved in shifting attention to newly located landmarks and integrating landmark locations into an existing mental representation of the map. In addition, the executive may contribute by combining and coordinating visuospatial and verbal information, as the current work suggests that map learning is a multimodal process. In contrast, simultaneous tasks may encourage simpler visuospatial encoding strategies, which require little executive input. The current results are consistent with previous work using other stimuli (Ang & Lee, 2008) and extend the role of the central executive to map learning. To the author's knowledge, the present research was the first to provide evidence that survey acquisition from maps is reliant on central executive processing.

The present findings are not consistent with previous work by Logie (Logie, 1995; Vecchi & Cornoldi, 1999) suggesting that activity demands greater executive resources than passive observation. According to Logie's model active learning relies on executive input to facilitate integration of new visuospatial information and to shift attention between new stimuli during learning (Coluccia, 2005; Rudkin et al., 2007). Following Logie’s model, executive interference should have impaired active learning to a greater extent than passive observation in Experiment 4 of this thesis. However, the results demonstrated that executive interference equally impaired active and passive learners. It follows that the current findings are not consistent with the assumption in Logie’s model that activity demands greater executive input than passive observation insofar as map learning is concerned.

A primary implication of the current data in the working memory domain is that all components contribute to map learning. Although it was expected that the visuospatial sketchpad is involved, it is less intuitive that verbal and central executive resources are required to obtain information from maps. The present results therefore highlight the notion that map learning is not an exclusively visuospatial in nature and suggest that non-spatial demands can interfere with ones’ ability to encode map information. This suggestion is important to acknowledge from both a theoretical and applied perspective. From a theoretical viewpoint, the results are consistent with the notion that the phonological loop and central executive may be of greater importance if maps are presented sequentially (Gathercole & Baddeley, 1999; Gathercole et al., 2004; Baddeley, 1983; Pazzaglia & Cornoldi, 1999). In addition, the phonological loop may be involved in subvocal rehearsal strategies while the central executive may coordinate and integrate multimodal (i.e., visuospatial & verbal) information. The current results support the use of verbal and executive interference tasks in the design of dual-task map learning experiments, where previously only visuospatial interference tasks might have been considered. Specifically, backwards counting and *n*-back tasks provide an alternative to traditional interference tasks used in map learning designs (i.e., spatial tapping and articulatory suppression) (Coluccia, 2005; Coluccia et al., 2007; Garden et al., 2002).

From an applied perspective, the current results suggest that sequential map learning tasks (e.g., navigating novel routes by GPS, Google maps) should not be conducted in parallel with other cognitively demanding tasks regardless of their modality. For example, the navigational skills of a transport vehicle driver may suffer if they are required to engage in communication (i.e., verbal) or conduct complex forward planning (i.e., central executive). The current research suggests that not only visuospatial processing demands, but also verbal and executive demands may detrimentally affect spatial learning (e.g., texting while driving, see Nunes & Recarte, 2002). Taken together these findings advance our understanding of working memory in map learning and provide new explanations for the roles of the verbal and central executive components in this domain.

15.3 Implications for map learning

There are several important implications of the present research in the map learning domain. First, the current findings suggest that pointing and drawing tasks provide valid and reliable measurement of survey knowledge acquired from maps. These tasks have been widely used in previous literature (Blades, 1990; Gardony et al., 2013; Ishikawa et al., 2008; Quin & Ralston, 1986; Smyth et al., 1988) and often incorporate nuanced assessment criteria. The results from this thesis support their further use, as pointing and drawing data typically showed a consistent pattern of performance. Given the coherence of allocentric (i.e., drawing) and egocentric (i.e., pointing) measures, the results support the notion that survey knowledge incorporates both of these aspects (see Allen, Kirasic, Dobson, long, & Beck, 1996; Coluccia, 2005).

A second important implication of the results for the map learning domain is that the effect of experimental manipulations were generally consistent across free and goal-driven exploration. This consistency is noteworthy because research into map learning often utilises free exploration (Coluccia, 2005; Coluccia et al., 2007; Thorndyke & Hayes-Roth, 1982; Zhang et al., 2014). It may be argued that free exploration does not emulate the importance of locating a particular goal as is often the case in the real-world use of maps. The current findings present evidence against this suggestion as it appears that free and goal-driven map learning lead to comparable results. However, it should be acknowledged that the results from this investigation only pertain to the effects of interactivity and cognitive load across both exploration methods. It is possible that other factors in map learning (e.g., display quality, display size) could differ between free and goal driven learning (Tan et al., 2006; Wilkening & Frabrikant, 2011). This possibility highlights an avenue for future research, as it is unknown whether the effect of other variables differ between free and goal-driven exploration.

The current investigation of visuospatial interference in map learning also provided the opportunity to devise a novel method of spatial tapping, which was utilised in Experiments 1, 5, and 6. To conduct spatial tapping, participants used their feet to touch cells within the matrix. This design contrasts with traditional spatial tapping, in which participants use their hands (Quin & Ralston, 1986; Smyth et al., 1988). The present experiments showed that performance is similarly affected regardless of whether hands (Knight & Tlauka, 2017) or feet (Experiments 1, 5 and 6) are used for spatial tapping. It follows that spatial tapping with one’s feet is an effective method to raise visuospatial load if participants’ hands are otherwise encumbered. Spatial tapping with one’s feet could enable otherwise impractical dual-task designs as participants can use their hands to engage in a primary learning task. The use of feet in spatial tapping could hence improve the capability of future spatial learning experiments.

15.4 Summary

The primary aim of this dissertation was to identify the role of interactivity in map learning. The investigation demonstrated that interactivity had an inconsistent effect on the acquisition of information from maps. A second aim was to test the hypothesis that cognitive load could provide an explanation for the lower than expected performance of active learners in past investigations of interactivity. Experiment 1 found support for this hypothesis as active learners were disadvantaged under high load. However, this result was not replicated under the same experimental conditions in Experiment 6. Taking these findings together with the previous literature (e.g., Chrastil & Warren, 2012; Sandamas & Foreman, 2007, 2014; Sandamas et al., 2009), it appears that while activity demands greater cognitive resources than passive observation this does not result in a reliable disadvantage even under high task load. In the working memory domain, the current results showed a clear contribution of the visuospatial sketchpad, phonological loop, and central executive. This finding suggests that sequential map learning is a multimodal exercise, which demands resources from all components of working memory. The present findings also make a methodological contribution by demonstrating that spatial tapping with one's feet interferes with spatial learning similar to traditional spatial tapping using one's hands (Quin & Ralston, 1986; Smyth et al., 1988).

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Appendix A

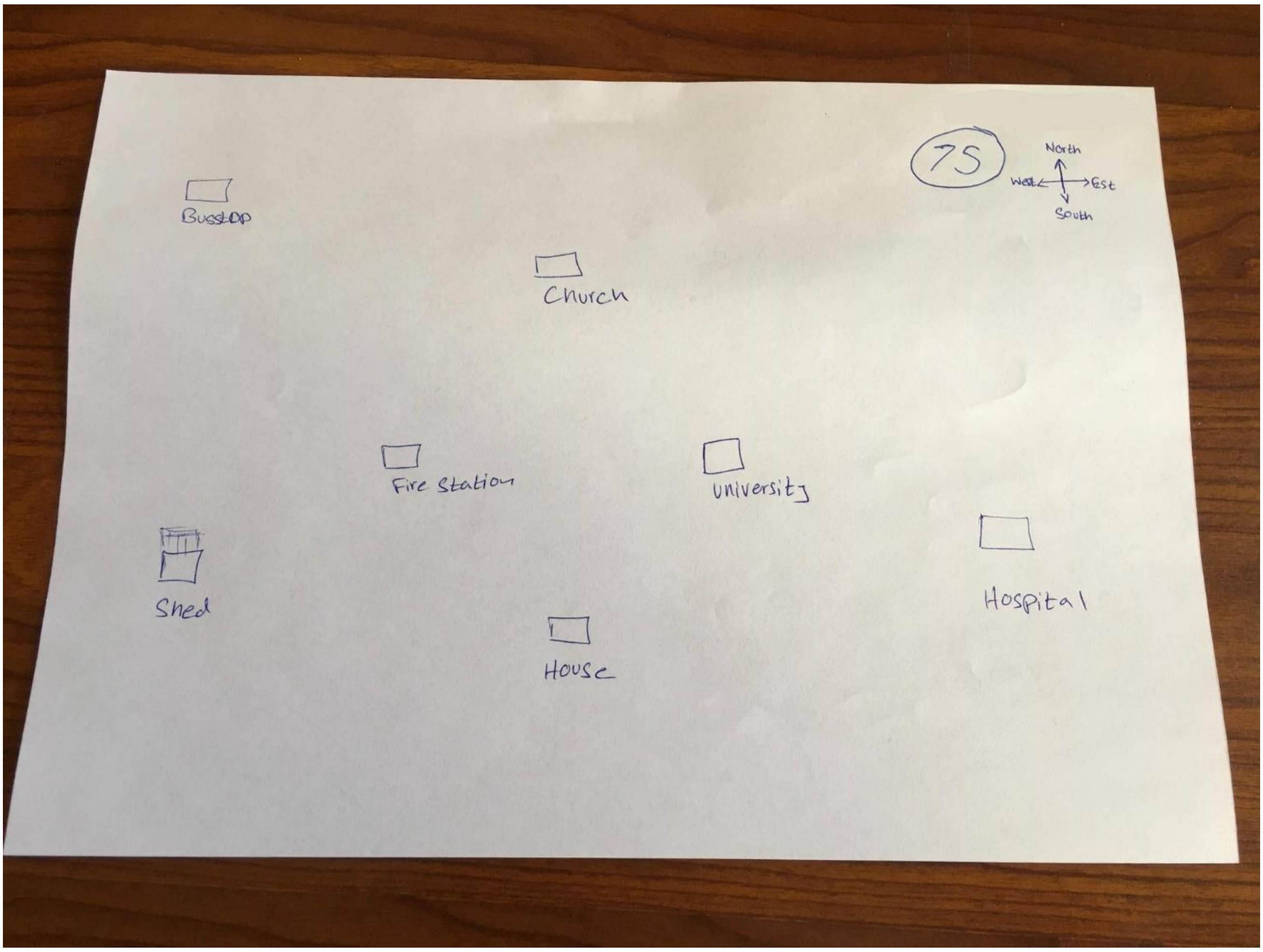
Device used by participants to complete the pointing task. The lower dial indicated the degrees (0 – 180) in which participants pointed left or right, the upper dial was not used.

Appendix B

Desk setup during the learning phase. Note the spatial tapping matrix was placed on the ground such that participants used their feet to tap the cells.

Appendix C

A map sketched by a participant to complete the drawing task. All maps were drawn in a "north up" orientation (see compass in top-right corner).



Appendix D

Dr Michael Tlauka

Letter of introduction

Dear Sir/Madam

I hold the position of senior lecturer in the School of Psychology at Flinders University. I would like to invite you to take part in a brief study which will last approximately 45 minutes. Matthew Knight will carry out the study. He will produce his student card, which carries a photograph, as proof of identity. Be assured that any information provided will be treated in the strictest confidence and that your data will not be individually identifiable. You are, of course, entirely free to discontinue your participation at any time or to decline to answer particular questions.

Please find below a brief outline of the nature of the research:

The focus of this experiment will be for a pair of participants to learn the spatial layout of a map. The map will be positioned on a desk underneath a sheet of cardboard. You will explore the map by looking through a hole in the cardboard. The cardboard will be moved by either yourself or the other participant, so the central hole exposes all regions of the map. Your goal is to learn the relative location of landmarks as accurately as possible. Try to keep in mind the location of landmarks relative to other landmarks (e.g., landmark A is south-east of landmark B). You may also perform a spatial tapping task while exploring the map, which involves continually tapping a matrix on the ground with your foot.

Your knowledge of the environment and the landmarks contained within it will then be tested in several tasks: a pointing task (moving a pointing device in the direction of specific landmarks) and a map-drawing task (drawing a map of the explored environment).

Any queries you may have concerning this project should be directed to me at the address given above or by telephone on (8201 2621), or e-mail (michael.tlauka@flinders.edu.au)

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee. The Secretary of this Committee can be contacted on 8201 3116, or e-mail human.researchethics@flinders.edu.au.

Thank you for your attention and assistance.

Yours sincerely,

Dr Michael Tlauka

Senior Lecturer

School of Psychology

Flinders University

Appendix E

CONSENT FORM FOR PARTICIPATION IN RESEARCH
(by experiment)

I …..

being over the age of 18 years hereby consent to participate as requested in the letter of introduction for the research project on Spatial Cognition.

1. I have read the information provided.
2. Details of procedures and any risks have been explained to my satisfaction.
3. I am aware that I should retain a copy of the Information Sheet and Consent Form for future reference.
4. I understand that:
    - I may not directly benefit from taking part in this research.
    - I am free to withdraw from the project at any time and am free to decline to answer particular questions.
    - While the information gained in this study will be published as explained, I will not be identified, and individual information will remain confidential.
    - Whether I participate or not, or withdraw after participating, will have no effect on any treatment or service that is being provided to me.
    - Whether I participate or not, or withdraw after participating, will have no effect on my progress in my course of study, or results gained.
    - I may ask that the recording/observation be stopped at any time, and that I may withdraw at any time from the session or the research without disadvantage.

Participant's signature……………………………………Date…………………...

I certify that I have explained the study to the volunteer and consider that she/he understands what is involved and freely consents to participation.

Researcher's name……………………………….…………………….................

Researcher's signature…………………………………..Date…………………….