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Map learning and working memory: Multimodal learning strategies

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The current research investigated whether learning spatial information from a map involves different modalities, which are managed by discrete components in working memory. In four experiments, participants studied a map either while performing a simultaneous interference task (high cognitive load) or without interference (low cognitive load). The modality of interference varied between experiments. Experiment 1 used a tapping task (visuospatial), Experiment 2 a backwards counting task (verbal), Experiment 3 an articulatory suppression task (verbal) and Experiment 4 an *n*-back task (central executive). Spatial recall was assessed in two tests, directional judgements and map drawing. Cognitive load was found to affect spatial recall detrimentally regardless of interference modality. The findings suggest that when learning maps people use a multimodal learning strategy, utilising resources from all components of working memory.

Keywords: working memory; spatial cognition; maps; multimodal learning

Acquiring spatial information from maps is a crucial skill for navigating in unfamiliar environments and for planning routes. The 'birds eye view' provided by maps offers an opportunity for learners to rapidly build upon their existing knowledge of an environment (Thorndyke & Hayes-Roth, 1982) and form large scale mental representations (i.e., survey knowledge). The widespread use of maps in popular applications (e.g., google maps, mounted GPS), highlights the importance of research into the nature of spatial information acquired from maps and the factors that determine how effectively this knowledge is acquired.

According to Montello (1993) maps are a crucial element of spatial learning as they represent large geographical spaces, which often cannot be viewed by personal locomotion. It has been observed that the spatial layout of large spaces can be more easily learned relying on maps than through navigation (Farrell et al., 2003; Moeser, 1988; Thorndyke & Hayes-Roth, 1982). For example, Moeser (1988) compared the spatial knowledge of long term employees of a hospital with a control group who were unfamiliar with it and studied a map of the hospital. The employees demonstrated inferior knowledge of the hospital, supporting the notion that maps facilitate the acquisition of mental representations of large environments.

Working memory

The present investigation focuses on the involvement of working memory in the processing of map stimuli. Working memory theory (Baddeley, Thompson, & Buchanan, 1975) stipulates that memory functions as a dynamic system, which manipulates and recalls information that is relevant to the task at hand. Research in this field has suggested that information of different modalities is managed by discrete components in working memory. The original model proposed by Baddeley and Hitch (1974) described a tripartite working memory structure. The visuospatial skeptchpad organises visual and spatial information including size, shape, speed and location. The phonological loop processes verbal and spoken material as well as abstract sound while the central executive controls attention, reasoning, and integration of information from the subcomponents. The three components are limited in their capacity to process information (Baddeley, 2002; Baddeley et al., 1975) as demonstrated by manipulation of cognitive load (Allen & Willenborg, 1998; Baddeley, Lewis, Eldridge, & Thompson, 1984). In the working memory model, cognitive load describes the number or complexity of tasks managed at a given moment. If simultaneous cognitive load exceeds the capacity of a component, then task performance diminishes (resulting in cognitive overload).

Experiments that investigate the contribution of working memory generally follow the dual task paradigm. In dual task experiments, participants conduct a primary learning task while concurrently performing an interference task (Garden, Cornoldi, & Logie, 2002; Picucci, Gyselinck, Piolino, Nicolas & Bosco, 2013). If the primary task and interference task compete for resources from the same component in working memory, then performance is reduced. If the primary and interference tasks load on different components, then primary task performance is maintained. The dissociation of working memory components has been demonstrated by dual task experiments (Baddeley & Andrade, 2000; Farmer, Berman, & Fletcher, 1986). For example, Baddeley and Andrade (2000) asked participants to mentally 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 affect performance. The decrement in recall indicates 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 in comparison with that of visual images. Verbal counting reduced the vividness of memory of musical notes, whereas spatial tapping did not. The results suggest that auditory memory for musical notes and verbal counting compete for processing in the phonological loop. This dissociative interference highlights the strength of dual task designs by enabling conclusions regarding the modality of specific tasks in working memory. For instance, if performance is negatively affected by visual or spatial interference, but not verbal interference, then the researcher may conclude the task loads on the visual spatial sketchpad.

Multimodal learning

The ubiquity of maps in settings that require multi-tasking (e.g., aircraft cockpit, car navigation) highlights the importance of research into which modalities contribute to map learning. Since maps are a visual stimulus it may be expected that map learning primarily relies on the visual spatial sketchpad. The contribution of the visuospatial sketchpad has received some attention (Coluccia, Bosco, & Brandimonte, 2007; Garden, et al., 2002; Knight & Tlauka, 2016). Garden et al. (2002) asked participants to memorise a sequence of images of a route from a bird's eye perspective which, taken together, portrayed a map. Participants learned the map while conducting spatial tapping or articulatory suppression (verbal) interference tasks, or without interference. The results showed that spatial interference detrimentally affected map learning to a greater extent than verbal interference. In a related experiment, Coluccia et al. (2007) had participants learn a map while undergoing similar spatial or verbal interference tasks, or without interference. Performance deteriorated following spatial interference, and was unaffected by verbal interference. The studies (Coluccia et al., 2007; Garden et al., 2002) indicate that the visuospatial sketchpad is involved in the processing of map stimuli.

Maps may also be encoded relying on a multimodal learning strategy, drawing on several components of working memory. Multimodal learning has been demonstrated in spatial learning tasks (Experiment 1, Garden et al., 2002; Hund, 2016; Meilinger, Knauff, & Bülthoff, 2008; Wen, Ishikawa, & Sato, 2011). For instance, Wen et al. (2011) had participants watch videos of a car journey in downtown Tokyo, while conducting visual, spatial or verbal interference tasks, or without interference. Participants were tested for their memory of the landmarks and routes explored in the video. Verbal and spatial interference was found to negatively affect spatial learning overall for participants with a high sense of direction. For those participants with a low sense of direction, verbal interference reduced landmark recall, but only visual interference affected memory for routes. The findings of Wen et al. imply that people with a high sense of direction employ a multimodal spatial learning strategy, incorporating verbal and visuospatial working memory. In contrast, those with low sense of direction use different encoding strategies, contingent upon the nature of spatial learning (e.g., learning landmarks or routes).

With respect to map learning Garden et al. (2002) observed that verbal interference negatively influenced knowledge acquisition, albeit to a lesser extent than spatial interference. In contrast, Coluccia et al. (2007) found that map learning was unaffected by verbal interference. Consequently, the findings of Garden et al. imply that the phonological loop contributes to map learning, while the findings of Coluccia et al. suggest that the phonological loop does not contribute.

One of the functions of the central executive is to integrate information from the subcomponents of working memory (Baddeley, 1983; 2002). Specifically, if the demands of a task overlap with the roles of the visuospatial sketchpad and the phonological loop, then the executive acts to coordinate and combine this information. To our knowledge the role of the central executive in map learning has not been examined. The executive has, however, been investigated in the context of other spatial learning tasks (e.g., Ang & Lee, 2008; Rudkin, Pearson, & Logie, 2007). Ang and Lee (2008) investigated the role of the central executive in children's spatial learning. Children completed several visuospatial primary tasks (i.e., Corsi blocks, letter rotation, paper folding), while simultaneously performing a random number generation task or in the absence of interference. Generating random numbers relies on executive resources (Towse & Neil, 1998) because it requires the monitoring of numbers in order to avoid repeating a previous sequence or producing a linear sequence (e.g., 1, 2, 3). This process entails maintenance of attention and reasoning, which are managed by the central executive. Random number generation was found to reduce performance on all three spatial primary tasks, suggesting that the executive plays a role in children's spatial reasoning. Similar results were found by Rudkin et al. (2007), who found that spatial learning in adults was negatively affected by executive interference. These findings reinforce the notion that spatial learning relies to some extent on the central executive.

In summary, this investigation examines whether map learning is based on a multimodal learning strategy, which relies on resources from all components of working memory. There is evidence that the visuospatial sketchpad is used in map learning (Coluccia et al., 2007; Garden, et al., 2002). However, the evidence for the role of the phonological loop in map learning is inconsistent. Garden et al. (2002) observed that map learning demanded verbal resources, whereas Coluccia et al. (2007) found no verbal contribution. The role of the central executive in map learning has not received attention.

In four experiments, we used a dual task design to increase people's cognitive load while learning a map. Participants explored a map in the presence of an interference task or in the absence of interference. The modality of interference task was altered between experiments such that interference selectively targeted a discrete component of working memory. Experiment 1 used a spatial tapping task, examining visuospatial memory. Two different verbal interference tasks were used in Experiments 2 (i.e., backwards counting) and 3 (i.e., articulatory suppression), which focused on the phonological loop. Experiment 4 used an *n*-back task, investigating the central executive.

Experiment 1

In Experiment 1, cognitive load was manipulated in the following manner: Participants in the high load group performed a spatial tapping task concurrently when exploring a map, while those in the low load group learned the map without interference. The experiment examined an additional factor (interactivity), which recently was found to be influenced by changes in cognitive load. Knight and Tlauka (2016) found that active learners were disadvantaged relative to passive observers when cognitive load was high, but not when load was low. Interactivity refers to the degree of control over exploration. In Experiment 1, active participants were responsible for physically controlling map exploration and making decisions about where to explore. In contrast, passive participants observed the map without controlling exploration.

Students were presented with a map which was covered by a sheet of cardboard with a small hole in the centre. The hole revealed a small portion (approx. 5%) of the map. Active participants controlled map exploration by moving the sheet of cardboard to look at different areas. Passive participants observed the map without communicating with the active participant. Spatial recall of the map was measured by a pointing task (i.e., "judgments of relative direction") and a drawing task.

It was hypothesised that map learning would be detrimentally affected by concurrent spatial tapping. This result would be consistent with past research, suggesting that map learning demands resources from the visuospatial sketchpad (Chrastil & Warren, 2012; Coluccia, 2005; Coluccia et al., 2007; Garden et al., 2002). Further, we expected that cognitive load would impair performance in active (but not passive) learners (Sandamas & Foreman, 2007; 2014; Sandamas, Foreman, & Coulson, 2009; Vecchi & Cornoldi, 1999).

Method

Participants

Eighty university students (61 females, 19 males) participated in the experiment in exchange for course credit or $15.

Design

In a 2 × 2 between-subjects design participants were tested in four groups, with cognitive load (low, high) and activity type (active, passive) as factors. Twenty participants were randomly allocated to each group. Note that the low cognitive load group from Experiment 1 was used as the control condition in all three experiments presented in this paper. Spatial learning was measured with a pointing task and a drawing task. Half of the directional judgments in the pointing task were aligned with the orientation in which the map was viewed (facing north) and the other half were contra-aligned (facing south). Response latencies and pointing errors were used as dependent measures in the pointing task. In the drawing task, participants sketched the map explored in the learning phase. Maps were evaluated by subjective ratings, the accuracy of landmark placement (in mm), and by recording the number of landmarks forgotten.

Materials

An A3 sized map (297mm × 420mm) (Figure 1) was used as the spatial learning stimulus. A sheet of cardboard (621mm × 755mm) was positioned to cover the map from participants' view in the learning phase. In the centre of the cardboard an 82×71mm hole was cut to reveal approximately 5% of the map at any given moment. The directions 'North', 'South', 'East', and 'West' were also indicated on the cardboard, with 'North' pointed toward the top of the map relative to participants' view. For the spatial tapping task an A4sized (210mm × 297mm) sheet of laminated paper with a 2×2 grid was used. In the four cells on the grid the digits 1-4 were presented in ascending order in a clockwise sequence (for a similar procedure see Farmer et al., 1986; Smyth, Pearson, & Pendleton, 1988). A pointing device was used to measure directional judgments in the pointing task. The device consisted of a pointer mounted on a tripod (height: 1.40 metres). The pointer could be rotated 360 degrees around the horizontal axis, providing a measure of response accuracy (in degrees). For the map drawing task the students were given an A4 sized sheet of paper to complete a freehand drawing of the map.

[Place Figure 1 here]

Figure 1. The map explored by participants in the learning phase. Note that the map was placed under a sheet of cardboard with a 82×71mm hole in the centre (relative size of the hole illustrated by the black rectangle).

Procedure

The experiment was conducted in two stages: a learning phase in which participants explored the map, and a testing phase which evaluated participants' memory of the map.

Learning phase

In the learning phase, students 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 the centre. Active participants physically moved the sheet of cardboard around the map such that the central hole revealed different areas. Passive participants were instructed to observe the areas shown without communicating with the active participant. The sitting position of active and passive participants (left versus right) was counterbalanced. Participants were asked to attend to the spatial relationship between the landmarks. Participants had two and a half minutes for map exploration (Thorndyke & Hayes-Roth, 1982).

Participants in the high load group performed a spatial tapping task concurrently while exploring the map, while those in the low load group learned the map without interference. The spatial tapping matrix was placed under the desk near participants' feet. To perform spatial tapping, participants used one foot to tap the numbers 1-4 in ascending order at the rate of one tap per second while the map was explored. The experimenter demonstrated the tapping procedure to ensure understanding. The experimenter corrected participants following any significant deviation in spatial tapping accuracy or speed. 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. Although spatial tapping is typically conducted with hands rather than feet, this was not possible because active learners' hands were used to control map exploration.

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. The experimental volunteers stood next to the pointing device and were asked to imagine standing at a landmark while pointing toward another landmark. For example, participants were asked "Imagine standing at the Fire Station facing north. Point to the University." Response latencies were recorded unobtrusively with a handheld digital stopwatch. 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 instructed to include the correct locations of landmarks and the spatial relationship between landmarks in their drawing (for a similar procedure see Blades, 1990; Waller, Loomis, & Steck, 2003). All participants drew “north up” maps and were asked to imagine that the border of the A4 drawing paper was the border of their map drawing. These instructions were intended to control rotation and scaling effects, which could otherwise distort map drawing accuracy (Friedman & Kohler, 2003). 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. Participants were given 1.5 minutes to complete their drawings. After the drawings were completed the experimenter recorded the number of landmarks forgotten (if any). If landmarks were forgotten, the experimenter requested that these landmarks be included in the participants’ map to his/her best estimation. Drawn 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 (in mm) between where participants placed landmarks and their true location. Placement errors were measured from the centre of a depicted landmark to the centre of the correct location such that the size of individual landmarks in participants’ drawings did not affect placement accuracy. This was accomplished 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 ps > .50). The data for participants tested first and second were therefore averaged.

Pointing task

Pointing errors and response latencies were analysed with a mixed ANOVA, with cognitive load (low load, spatial tapping) and activity type (active, passive) as between subjects factors and alignment (aligned, contra-aligned) as within subjects factor.

Pointing errors indicated a main effect of cognitive load, $F(1, 76) = 13.22$, $p < .001$, *partial* $\eta^2 = .15$, with participants in the low load group ($M = 46°$, $SD = 23°$) being more accurate in their pointing judgments than participants in the spatial tapping group ($M = 65°$, $SD = 21°$). Interactivity did not produce a reliable main effect, $F(1, 76) = .73$, $p = .39$. A significant alignment effect, $F(1, 76) = 39.69$, $p < .001$, *partial* $\eta^2 = .34$, showed that participants produced more accurate aligned pointing judgments ($M = 41°$, $SD = 22°$) than contra-aligned judgements ($M = 70°$, $SD = 39°$). No interactions approached significance (all *ps* > .05). Task performance across the four experiments is presented in Table 1.

Table 1

Pointing task and drawing task performance across cognitive load and interference modality. Standard deviations are shown in parentheses.

	Experiments				
	Experiment 1		Experiment 2	Experiment 3	Experiment 4
Dependent Variables	(Low Load)	(Spatial Tapping)	(Backwards Counting)	(Articulatory Suppression)	(*n*-back)
Pointing Errors (degrees)	46° (23°)	65° (21°)	71° (15°)	58° (21°)	66° (21°)
Response Times (seconds)	6 (1.7)	7.4 (4.1)	6.4 (2.6) *ns*	6.3 (2.7) *ns*	6.8 (3.3) *ns*
Subjective Ratings	5.7 (2.6)	3.9 (2.7)	3 (1.8)	4.1 (2.4)	2.6 (1.8)
Drawing Errors (mm)	39 (19)	59 (32)	75 (26)	61 (27)	77 (33)
Landmark Recall	.2 (.4)	.6 (.9)	.9 (.8)	.8 (.8)	.7 (.8)

Note. The same low cognitive load group was used as a control group in all four experiments. In the table above *"ns"* indicates that the given value did not differ statistically from the low load control group ($p > .05$).

Response latencies showed a reliable effect of cognitive load, $F(1, 76) = 4.03$, $p = .048$, *partial* $\eta^2 = .05$. Participants in the low load group ($M = 6.0$, $SD = 1.8$) responded more quickly than participants in the spatial tapping group ($M = 7.4$, $SD = 4.1$). Interactivity did not result in a reliable effect, $F(1, 76) = .337$, $p = .56$. An alignment effect, $F(1, 76) = 37.18$, $p < .001$, *partial* $\eta^2 = .33$, reflected the finding that participants responded faster to aligned questions ($M =$ 5.6

seconds, *SD* = 3.4 seconds) than contra-aligned questions (*M* = 7.8, *SD* = 3.8). All interactions were non-significant (*p*s > .05).

Drawing task

Between-subjects ANOVAs were used for the drawing task data, with cognitive load (low load, spatial tapping) and activity type (active, passive) as factors. These analyses were run separately for subjective ratings, landmark placement errors, and landmark recall.

Two double blind raters evaluated the accuracy of drawn maps on a 1-10 scale. Higher scores indicated greater accuracy. The raters' evaluations demonstrated strong reliability, $r(78) = .87$, $p < .001$, and were averaged into a single subjective evaluation score. A main effect of cognitive load, $F(1, 76) = 9.57$, $p = .003$, *partial* $\eta^2 = .112$, demonstrated that the spatial tapping group (*M* = 3.89, *SD* = 2.69) were evaluated as less accurate than the low load group (*M* = 5.71, *SD* = 2.62). Both the effect of interactivity, $F(1, 76) = .002$, $p = .97$, and the interaction between cognitive load and interactivity, $F(1, 76) = 2.87$, $p = .09$, were non-significant.

Landmark placement errors indicated a main effect of cognitive load, $F(1, 76) = 11.52$, $p = .001$, *partial* $\eta^2 = .13$, as participants in the low load group produced more accurate maps (*M* = 39mm, *SD* = 19mm) than participants in the spatial tapping group (*M* = 59mm, *SD* = 32mm). Interactivity did not produce a significant effect, $F(1, 76) = 3.32$, $p = .07$. Likewise, the interaction between interactivity and cognitive load was non-significant, $F(1, 76) = 1.72$, $p = .19$.

Landmark recall data revealed a reliable effect of cognitive load, $F(1, 76) = 8.14$, $p = .006$, *partial* $\eta^2 = .097$, showing that participants in the spatial tapping group (*M* = .6, *SD* = .9) forgot a greater number of landmarks than participants in the low load group (*M* = .2, *SD* = .4). The effect of interactivity was not significant, $F(1, 76) = 3.41$, $p = .07$, but the interaction between cognitive load and interactivity was significant, $F(1, 76) = 4.76$, $p = .03$, *partial* $\eta^2 = .06$. Simple main effects tests (Bonferroni corrected) demonstrated that in the active group, spatial tapping participants recalled fewer landmarks ($M = .2$, $SD = .4$, $p = .001$) than low cognitive load participants ($M = .9$, $SD = 1.1$). In contrast, in the passive group cognitive load did not affect performance (spatial tapping $M = .3$, $SD = .5$; low load $M = .2$, $SD = .4$, $p = .64$).

Discussion

The results from Experiment 1 demonstrate that map learning deteriorated in the presence of visuospatial interference. In the pointing task, pointing errors and response latencies were increased by spatial tapping by comparison with the low cognitive load group. In the map drawing task, subjective ratings and landmark placement errors were negatively affected by spatial tapping. Landmark recall was also worse in the spatial tapping group, but this effect was moderated by interactivity.

Overall, the findings are consistent with the hypothesis that a visuospatial task interferes with map learning. The results are in agreement with earlier findings, which have shown that spatial learning ability is limited by the processing capacity of the visuospatial sketchpad (Coluccia et al., 2007; Garden et al., 2002). The results also show that like spatial tapping with one's hands (Coluccia et al., 2007; Garden et al., 2002; Knight & Tlauka, 2016) spatial tapping with one's feet had a detrimental effect on map learning.

The interaction between cognitive load and interactivity observed in landmark recall revealed that active participants were affected by an increase in visuospatial load. In contrast, passive participants maintained similar landmark recall in the high and low load groups. This result is consistent with Knight and Tlauka (2016), who demonstrated an active disadvantage in map learning under high (but not low) cognitive load. Active participants may be disadvantaged due to the greater cognitive demand of controlling map exploration compared to the low demand of passive viewing (Chrastil & Warren, 2012; Sandamas & Foreman, 2007; 2014; Sandamas et al., 2009; Taillade et al., 2013). Passive participants may have more cognitive resources available, making them better equipped to cope with high visuospatial demand than active learners. We interpret this result to show that interactivity can moderate the effects of visuospatial load in some measures of learning.

The pointing task revealed a reliable alignment effect, with aligned pointing judgments (i.e., north facing) being considerably more accurate (approx. 29°) than contra-aligned judgments (i.e., south facing). This finding is consistent with previous work, which has shown that maps produce orientation-specific mental representations (Montello, 2010; Thorndyke & Hayes-Roth, 1982). Pointing judgments which are not aligned with the initial orientation require mental rotation, reducing recall accuracy (Evans & Pezdek, 1980; Levine, Jankovic, & Palij, 1982; Sholl, 1987; Tlauka, 2006).

Experiment 2

Experiment 1 found evidence consistent with the notion that map learning relies on resources from the visuospatial sketchpad. In Experiment 2, the focus was on the phonological loop and the role of verbal information in map learning. The experimental design was identical to Experiment 1, albeit the modality of interference in the high load group was altered. High load participants were asked to conduct simultaneous backwards counting during learning as opposed to the spatial tapping interference task used in Experiment 1. Counting aloud has been shown to demand resources from the phonological loop (Baddeley & Andrade, 2000). Participants were required to maintain a predictable sequence of numbers in working memory and verbalise the correct number in the sequence. As discussed earlier the effect of verbal load on map learning (Coluccia et al., 2007; Garden et al., 2002) has been found to be inconsistent, and it is thus not clear whether verbal interference reduces map learning ability.

Method

Participants

Forty participants (31 females, 9 males) were recruited who took part in exchange for $15 or course credit. These new participants were allocated to the verbal interference group. Their performance was compared to the low cognitive load control group from Experiment 1.

Design

The experimental design was identical to Experiment 1 with the exception that participants in the high load group conducted a backwards counting interference task. As in Experiment 1 interactivity was included as a factor.

Procedure

The procedure in the learning phase differed from Experiment 1 in that participants in the high cognitive load group performed a backwards counting interference task in the learning phase. The experimental volunteers were instructed to count backwards from 100 in steps of three. Active and passive participants were required to complete backwards counting simultaneously, so participants took turns verbalising the sequence, i.e., the active participant would state the numbers “97, 94, 91”, and then the passive participant would continue with “88, 85, 82” etc. In this way, each participant performed two subtractions before the other participant continued the sequence. The experimenter ensured that the sequence was maintained in a timely manner (approx. 1 response per second) and pointed out any incorrect responses. Whether the active or passive participant initiated the counting sequence was counterbalanced.

Results

Independent sample t-tests showed that the dependent measures were unaffected by test order (all *p*s > .22). Data for participants tested first or second in the pointing task were therefore averaged in the following analyses.

Pointing Task

Analysis of absolute pointing errors revealed a main effect of cognitive load, $F(1, 76) = 31.78$, $p < .001$, *partial* $\eta^2 = .30$. Participants in the low load group ($M = 46°$, $SD = 23°$) were more accurate in their pointing judgments than participants in the verbal interference group ($M = 71°$, $SD = 15°$). Alignment was found to be significant, $F(1, 76) = 30.68$, $p < .001$, *partial* $\eta^2 = .29$, reflecting the finding that participants pointed more accurately from an aligned perspective ($M = 47°$, $SD = 22°$) than from a contra-aligned perspective ($M = 70°$, $SD = 36°$). The main effect of interactivity was not significant, $F(1, 76) = .51$, $p = .48$, and no interactions approached significance (*p*s > .05).

For the response latency data, both the main effect of cognitive load, $F(1, 76) = .50$, $p = .48$, and interactivity, $F(1, 76) = .14$, $p = .70$, were not significant. A main effect of alignment, $F(1, 76) = 71.45$, $p < .001$, *partial* $\eta^2 = .49$, demonstrated that participants answered aligned pointing questions ($M = 5.1$ seconds, $SD = 1.7$ seconds) faster than contra-aligned questions ($M = 7.2$, $SD = 3.1$). All interactions were non-significant (*p*s > .05).

Drawing Task

To acquire subjective ratings, participants' drawings were rated on a 1-10 scale by two double-blind raters, with higher scores indicating 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 maps of participants in the verbal interference group ($M = 3.00$, $SD = 1.79$). In contrast, interactivity did not result in 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 task complexity was also not statistically reliable, $F(1, 76) = 1.49$, $p = .23$.

Discussion

The results from Experiment 2 demonstrated a consistent decrement in map learning following high load during learning. In the pointing task, interference resulted in higher pointing errors relative to the (low cognitive load) control group. Likewise, in the drawing task participants engaged in backwards counting drew maps which were rated as lower in accuracy, displayed poorer landmark placement, and were more likely to forget landmarks. Unlike Experiment 1, no measures revealed an interaction between cognitive load and interactivity.

Experiment 3

In Experiment 2, the interference task employed to raise cognitive load was backwards counting. It can be argued that the central executive is involved in the mental arithmetic and cognitive updating required in backwards counting (Miyake et al., 2000; Yang et al., 2016). As a result, it is not possible to conclude that participants relied on the articulatory loop alone to process the interference task used in Experiment 2. Experiment 3 addresses this issue by employing articulatory suppression to increase cognitive load.

Articulatory suppression consists of repeating nonsense words or syllables such that verbal resources are engaged in task-irrelevant verbalisation (Baddeley et al., 1975). It has been shown that people's ability to subvocalise information (i.e., linguistic mental rehearsal) is impaired by articulatory suppression (Baddeley, 1983; Chrastil & Warren, 2012; Garden et al., 2002), and articulatory suppression has been used in working memory studies to examine 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, decision making or responding to stimuli, the rationale underlying Experiment 3 is that no demand should be exerted on the central executive (Yang et al., 2016).

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.

Design

The experimental design was identical to the previous experiments except that an articulatory suppression task was used in the high load group. As in Experiments 1 and 2 interactivity was included as a factor.

Procedure

The map learning procedure was identical to the 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 to 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 al., 1984; Irrazabel, Saux, & Burin, 2016), in which repeated verbalisation of irrelevant words has been used to raise verbal load.

Results

Independent sample t-tests indicated 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 those tested first, t(64.90) = 2.09, $p = .04$, $d = .47$.

Pointing Task

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

For the response latency data, both cognitive load, $F(1, 76) = .40$, $p = .53$, and interactivity, F(1, 76) = .30, $p = .59$, were not significant. A significant alignment effect, $F(1, 76) = 61.70$, $p < .001$, *partial* $\eta^2 = .45$, showed that participants answered aligned pointing questions ($M = 5.1$ seconds, $SD = 1.7$ seconds) faster than contra-aligned questions ($M = 7.3$, $SD = 3.3$). No interactions approached significance (*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. Cognitive load revealed a significant main effect in subjective ratings, $F(1, 76) = 7.75$, $p = .007$, *partial* $\eta^2 = .09$, showing that the maps of the low load group ($M = 5.71$, $SD = 2.62$) were rated as more accurate than maps of those 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 cognitive load and interactivity did not approach significance, $F(1, 76) = 1.76$, $p = .19$.

For landmark placement errors, cognitive load was significant, $F(1, 76) = 16.89$, $p < .001$, *partial* $\eta^2 = .18$. Low load participants drew more accurate maps (M = 39mm, SD = 19mm) than participants engaged in articulatory suppression (M = 61mm, SD = 27mm). Interactivity did not indicate a reliable effect, $F(1, 76) = 1.36$, $p = .25$. The interaction between cognitive load and interactivity was also not significant, $F(1, 76) = .36$, $p = .55$

The landmark recall data indicated a main effect of cognitive load, $F(1, 76) =15.16$, $p < .001$, *partial* $\eta^2 = .17$. Fewer landmarks were forgotten by participants in the low load group ($M = .2$, $SD = .4$) by comparison with participants in the articulatory suppression group ($M = .8$, $SD = .8$). Interactivity did not lead to a significant effect, $F(1, 76) = .03$, $p = .87$, nor did the interaction between interactivity and verbal load, $F(1, 76) = .26$, $p = .61$.

Discussion

A consistent detrimental effect of verbal load was observed. In the pointing task articulatory suppression impaired accuracy while in the drawing task, subjective evaluations and drawing errors were negatively affected by articulatory suppression relative to no interference. Those engaged in articulatory suppression also forgot to include a greater number of landmarks in map drawings by comparison with low load participants. As in Experiment 2, no measures revealed an interactivity effect or an interaction between interactivity and verbal load.

The purpose of Experiment 3 was to determine whether a verbal interference task, which does not draw on resources from the central executive, would impair map learning. It has been suggested that both backwards counting (Experiment 2) and spatial tapping (Experiment 1) rely on input from the central executive (Yang et al., 2016). Both tasks require maintained attention and forward planning, which are functions of the central executive (Baddeley, 1983; Baddeley, 2002; Sandamas & Foreman, 2014). Experiment 3 demonstrated that map learning was impaired by simple repetition of an irrelevant word (i.e., articulatory suppression), a verbal task which does not require processing in the central executive. Overall, it appears 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.

Experiment 4

The results from Experiments 1-3 are consistent with the notion that verbal and visuospatial resources are involved in encoding map information, suggesting that a multimodal encoding strategy is employed in the acquisition of knowledge acquired from maps. Experiment 4 was designed to examine the potential contribution of the central executive. One of the functions of the central executive is to integrate information from the subcomponents of working memory (Baddeley, 1983, 2002). Specifically, if the demands of a task overlap with the roles of the visuospatial sketchpad *and* the phonological loop, then the executive acts to organise and combine this information (Gathercole, Pickering, Ambridge, & Wearing, 2004; Hitch & Baddeley, 1976). Given the results from Experiments 1-3, which showed that concurrent visuospatial and verbal tasks interfered with map learning, the executive may be expected to play a role in map learning by combining acquired multimodal (i.e., visuospatial and verbal) information.

Experiment 4 investigated the effect of executive load using a central executive interference task. An *n*-back task was employed in which participants were required to remember letters in a sequence and make judgments as to whether certain letters had appeared previously. The *n*-back was chosen because it requires participants to constantly refresh a series of letters held in memory, relying on a dichotomous ("yes/no") decision. Letters were presented in an unpredictable order such that each required an immediate and specific response. The demands of the *n*-back task ensured that load was primarily exerted on the central executive (Baddeley, 2002; Morris & Jones, 1990), which is assumed to manage decision processes and sustained attention (for more details on the *n*-back task, see Morris & Jones, 1990). To our knowledge this experiment is the first to focus on the role of the executive in map learning.

Some research suggests that central executive load is in higher demand by active relative to passive learners (Coluccia, 2005; Taillade et al., 2013; Vecchi & Cornoldi, 1999). The rationale is that active learning requires greater manipulation of information in working memory, which may demand input from the executive. This notion was tested by Vecchi and Cornoldi, who asked young and old participants to conduct active (e.g., solving puzzles) and passive (e.g., visual image recall) visuospatial exercises. 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 attributed this discrepancy to age-related decline in central executive function, which may detrimentally affect performance in active tasks. Vecchi and Cornoldi's findings suggest that in the current design, active subjects may be negatively affected by high executive load to a greater extent than passive subjects because passive observers may have greater executive resources available.

Method

Participants

Forty university students were recruited (29 females, 11 males) and were awarded with course credit or $15. Their performance was compared with the low cognitive load group from Experiment 1.

Procedure

The map learning design was identical to Experiments 1 and 2, but an *n*-back task was used to interfere with map learning. To complete the *n*-back task participants were told that they would be read aloud a series of letters by the experimenter. Participants were required to state whether each letter in the sequence matched or did not match the letter that came two spaces before (i.e., a 2-back design). A “yes” response indicated that the letter matched, whereas a “no” response indicated that the letters did not match. As participants completed the *n*-back task in active and passive pairs, participants interchanged responses after every second letter. For example, the experimenter might read aloud the letters “A, Y, A, P, S, P”. The first participant would respond “yes” to the third letter in the series (A) because this matched the letter that came two spaces before, but would answer “no” to the fourth letter (P) because this was preceded two spaces before by the letter “Y”. The second participant would then respond to the following two letters (i.e., “S” and “P”). Participants would continue interchanging responses after every second letter for the duration of the study phase. The experimenter practiced the *n*-back task with participants to ensure understanding before the study phase began. During the study phase, the experimenter would point out any errors to participants to ensure focus was maintained on the *n*-back task. Interactivity was manipulated in the same way as the previous experiments. Active participants controlled map exploration via the sheet of cardboard, while passive participants observed without communicating with their active partner. After completing the learning phase participants undertook the pointing and drawing tasks.

Results

Independent samples t-tests confirmed that testing order did not influence performance (all *p*s $> .05$).

Pointing Task

Pointing errors demonstrated a reliable effect of cognitive load, $F(1, 76) = 14.53$, $p < .001$, *partial* $\eta^2 = .16$. 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, $F(1, 76) = .382$, $p = .53$. An effect of alignment, $F(1, 76) = 46.45$, $p < .001$, *partial* $\eta^2 = .25$, showed that participants responded more accurately to aligned questions ($M = 32°$, $SD = 18°$) than to contra aligned questions ($M = 55°$, $SD = 34°$). All two and three-way interactions were not significant (*ps* $> .05$).

For response latencies, neither cognitive load, $F(1, 76) = 1.67$, $p = .20$, nor interactivity, $F(1, 76) = .38$, $p = .54$, produced significant effects. However, the effect of alignment was significant, $F(1, 76) = 59.31$, $p < .001$, *partial* $\eta^2 = .44$, as participants responded faster to aligned pointing questions ($M = 5.3$ seconds, $SD = 2.3$ seconds) than contra-aligned questions ($M = 7.46$, $SD = 3.51$). 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 score. The effect of cognitive load was found to be statistically reliable, $F(1, 76) = 38.74$, $p < .001$, *partial* $\eta^2 = .34$, 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 cognitive load group ($M = 5.71$, $SD = 2.62$). The effect of interactivity on subjective ratings was not significant, $F(1, 76) = 3.45$, $p = .07$, nor was the interaction between activity type and cognitive load, $F(1, 76) = .010$, $p = .92$.

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

The landmark recall data also showed a significant effect of cognitive load, $F(1, 76) = 14.60$, $p < .001$, *partial* $\eta^2 = .16$. Participants in the low load group ($M = .2$, $SD = .4$) forgot significantly fewer landmarks than participants in the central interference group ($M = .7$, $SD = .8$). In contrast, landmark recall was not affected by interactivity, $F(1, 76) = .48$, $p = .49$, and the interaction between interactivity and cognitive load was not significant, $F(1 , 76) = .12$, $p = .73$.

Discussion

The results demonstrated a reliable effect of central executive interference. The pointing task revealed lower accuracy in the *n*-back group relative to the low cognitive load group. Participants' map drawings were negatively affected by central executive interference, which was evident in subjective ratings, landmark placement errors, and landmark recall. The deterioration in performance following interference from the *n*-back task suggests that map learning relies to some extent on the central executive. The executive plays an important role in combining visuospatial and verbal information when task demands overlap both subcomponents. Given that no difference was observed between active and passive subjects, the current findings suggest that executive demand in map learning is similar regardless of interactivity.

General Discussion

In four experiments, participants explored a map either while conducting a simultaneous interference task or in the absence of interference. Only the modality of interference was altered between experiments such that each experiment evaluated cognitive load on a discrete component of working memory. The main result was that map learning was detrimentally affected by visuospatial, verbal, and central executive concurrent tasks. Alignment effects were also found, demonstrating an advantage in the pointing task for aligned over contra aligned judgments. Overall, our findings suggest that map learning demands resources from all components of working memory.

Experiment 1 showed that visuospatial interference impaired map learning. This finding is consistent with previous research (Coluccia, 2005; Coluccia et al., 2007; Garden et al., 2002), indicating that map learning is reliant on visuospatial working memory. Experiment 1 also examined the potential effect of interactivity on recall and revealed a pattern which was not found in Experiments 2-4. The comparison of active and passive participants indicated that interactivity can influence the effect of visuospatial interference. Active participants forgot a greater number of landmarks following visuospatial interference whereas the landmark recall of passive participants was unaffected by cognitive load. This finding is consistent with earlier results (Knight & Tlauka, 2016) and is in agreement with the notion that activity demands greater cognitive effort than passive observation. Active learners may be disadvantaged when visuospatial resources are in high demand (Chrastil & Warren, 2012; Sandamas & Foreman, 2007; 2014; Sandamas, et al., 2009). The active disadvantage was not found when load was raised on verbal and central executive working memory in Experiments 2- 4, suggesting that the effect was not caused by a generic increase in cognitive load. Rather, increased demand on the visuospatial sketchpad resulted in a performance cost for active learners.

The results from Experiment 2 and 3 indicated that verbal interference also adversely affected spatial recall. In the experiments, participants may have internally rehearsed phrases (see Figure 1) such as “The shed is southwest of the fire station”. Previous work has suggested that subvocalisation is processed in the phonological loop (Baddeley, 1983; Chrastil & Warren, 2012; Hund, 2016). The present findings are consistent with the notion that subvocalisation in combination with other visuospatial strategies (e.g., visualizing the locations of landmarks) facilitates map learning.

Our findings are in agreement with Garden et al.’s study (2002) who reported that verbal interference had a detrimental effect on recall, but are at odds with Coluccia et al. (2007) who observed that map learning was unaffected by verbal interference. The reason for the conflicting outcomes with respect to the involvement of the phonological loop in spatial recall are yet to be determined. One explanation for this discrepancy is that Garden et al. used a map learning procedure in which participants were gradually exposed to the map (i.e., sequential viewing). This procedure is similar to that used in the current design, in which the map was explored by gradually revealing different areas through the central hole in the cardboard. In contrast, Coluccia et al. had participants view the entire map at once (i.e., simultaneous viewing). It is possible that verbal memory is relied upon to a greater extent for sequential tasks (Chrastil & Warren, 2012), which could explain why the phonological loop had an effect in this study and in Garden's et al. experiment.

To our knowledge Experiment 4 is the first to provide evidence for the role of the executive in map learning. Other research has found that the executive contributes to visuospatial abilities in children (Ang & Lee, 2008) and adults (Rudkin et al., 2007) including mental rotation, spatial visualisation, and encoding sequential movements. The present study suggests that increasing central executive load diminishes our capacity to perform complex spatial tasks. Our findings are in agreement with earlier investigations (Gathercole, et al., 2004; Miyake et al., 2000) and extend the role of the executive to the map learning domain. One interpretation is that the executive was involved in map learning due to its capacity to combine visuospatial and verbal information in multimodal tasks.

In addition to being used in the processing of multimodal tasks it is possible that the central executive is relied upon in processing sequential spatial tasks. Previous work by Rudkin et al. (2007) has suggested that the central executive may be critical in processing spatial sequential information. Rudkin et al. arrived at this conclusion by conducting a dual task experiment, in which participants were asked to complete several spatial tasks. Some of these tasks were sequential (e.g., Corsi blocks) while others were simultaneous (e.g., Matrix patterns). While completing these primary tasks participants were also engaged in executive interference (i.e., random number generation). It was observed that performance in sequential tasks deteriorated to a greater extent when compared to simultaneous tasks. Rudkin's et al. findings suggest that sequential tasks are reliant on resources from the central executive. This reliance on the executive may be caused by the requirement in sequential tasks to integrate new information with previously acquired information (Baddeley, 2002). In contrast, no such integration is required in simultaneous tasks. In the current design, it is possible the central executive is used to integrate visuospatial information acquired over the course of map exploration (e.g., the locations of landmarks). It is noteworthy that the sequential processing explanation is consistent with our interpretation of Experiments 2 and 3, specifically that verbal memory is involved in processing sequential information.

An alternative explanation for the current results is to attribute the findings to a generic dual task interference effect rather than to modality specific interference. According to this account map learning is cognitively demanding such that any concurrent task has the potential to impair map recall. While we cannot exclude this possibility, we note the dissociation of visuospatial interference (Experiment 1) in comparison to that of other modalities (Experiments 2-4) in relation to interactivity. More specifically, our findings indicated an interaction between interactivity and visuospatial load in Experiment 1, whereas no such interaction was found in subsequent experiments. This interaction replicated an earlier experiment (Knight & Tlauka, 2016), which also found that interactivity was moderated by visuospatial load. Given that visuospatial load produced a different pattern of results in comparison with verbal and executive load, it appears that the present experiments were sensitive to modality specific demands.

Multimodal learning has been demonstrated in other survey learning tasks (Garden et al., 2002; Meilinger et al., 2008; Wen et al., 2011). Meilinger et al. and Wen et al. found that simulated route learning required a multimodal learning strategy, incorporating both visuospatial and verbal memory. It is possible that map learning relies on a similar multimodal strategy due to the necessity to integrate piece-wise spatial information into a survey representation. The integration process involved in survey learning may be facilitated by verbal and executive memory, suggesting that survey learning may be a multimodal exercise regardless of the manner in which information is obtained (e.g., from maps or from navigation). This is significant because map learning involves allocentric (i.e., "bird's eye view) survey acquisition, whereas an egocentric perspective is used if survey knowledge is obtained by route navigation (Thorndyke & Hayes-Roth, 1982).

The lack of interactivity effects observed in the current experiments is noteworthy. Typically, an active advantage is expected in spatial learning tasks (Chrastil & Warren, 2012; Sandamas & Foreman, 2007; 2014; Sandamas et al., 2009; Wilson & Péruch, 2002). The present findings do not support the notion that activity is advantageous to map learning, as active and passive learners generally showed similar map recall (Experiments 2-4). However, an effect of interactivity was identified in Experiment 1, in which active learners were disadvantaged under high visuospatial load. A plausible explanation is that passive observes have greater visuospatial resources available and are hence better equipped to cope with high visuospatial load (see Knight & Tlauka, 2016).

Chrastil and Warren (2013) examined interactivity in the context of survey learning in a virtual environment. They found that some components of activity were not beneficial (i.e., decision making, vestibular feedback) whereas others facilitated learning (i.e., visual, motor and proprioceptive information). The authors concluded that that activity may only be beneficial if visual and motor/proprioceptive information is emphasised. Although Chrastil and Warren's investigation focused on the components of activity rather than the effects of interference, their findings are broadly consistent with the present results. Both this study and Chrastil and Warren are consistent with the assumption that the potential benefit of activity in survey learning is context dependent (also see Attree, et al., 1996). The present research suggests that high visuospatial load negatively affects active learning, whereas Chrastil and Warren's findings imply that only certain components of activity are beneficial over passive observation.

In summary, the four experiments presented here suggest that map learning involves a multimodal learning strategy, demanding resources from all components of working memory. The results are consistent with the notion that visuospatial working memory is critical in map learning. Our findings also point to a contribution of the phonological loop, possibly due its role in subvocal rehearsal of spatial relationships on the map, and to that of the central executive, which may contribute by combining visuospatial and verbal information.

Disclosure of interest

The authors declare no conflicts of interest.

Word count: 9302

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