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Interactivity in map learning: The effect of cognitive load

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Abstract

The hypothesis that active learning is beneficial relative to passive observation was assessed in the context of spatial knowledge derived from maps. Active and passive participants studied a map either while performing a simultaneous spatial tapping task (high cognitive load) or in the absence of this task (low cognitive load). Active participants controlled how the map was learned, with passive participants observing map learning without exercising control. Spatial recall was assessed in two tests, directional judgements and map drawing. Map drawing and directional judgments showed a similar pattern of results, with performance detrimentally affected by a high load for active participants, but not for passive participants. The results indicate that activity and cognitive load interact, suggesting that active learning can be detrimental to spatial learning in cognitively demanding tasks.

Spatial navigation and learning to orientate oneself in a novel environment are key cognitive skills, allowing us to function in everyday life. Some researchers have argued that spatial memory is enhanced by active learning relative to passive observation. For example, Appleyard (1970) noticed that bus drivers could draw survey type maps with relative accuracy, whereas bus commuters were only able to produce more simplistic route drawings. The observation implied that the navigational control exercised by bus drivers increased the accuracy of their spatial memories relative to the passive commuters.

This investigation further examines interactivity in spatial memory. We use 'interactivity' as a generic term which encompasses both activity and passivity. Active spatial learning can be defined by a number of distinct components, e.g., decision-making such as identifying the shortest route to a destination and the carrying out of an action such as following a path determined by a GPS (for a distinction between decision-making and movement control see Farrell et al., 2003; von Stülpnagel & Steffens, 2013). In contrast, passive learning is characterised by the absence of navigational control such that the environment is observed rather than manipulated (e.g., following a tour group through an unknown city).

In the experiment presented here interactivity is manipulated in the context of spatial knowledge derived from maps. Studying physical maps has been shown to be an effective strategy to develop survey knowledge, as maps encourage an allocentric perspective which emphasises the spatial relationships of and distances between landmarks (Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006). Maps are a widely used medium for spatial knowledge acquisition (Tlauka & Nairn, 2004) and they are an important orientation aid employed in a variety of situations such as piloting (Aretz, 1991) and driving (Liu, 2001).

Given the ubiquity of map displays, the question of whether the manner of interaction with a map (active versus passive) affects learning becomes an important one.

To our knowledge there is no research into interactivity in spatial learning derived from maps. This paper addressed the lack of research in this area by looking at the potential interaction between interactivity and cognitive load. Cognitive load is determined by the number of items of information processed simultaneously in working memory (e.g., Garden, Cornoldi & Logie, 2002; Vecchi & Cornoldi, 1999), with performance typically diminishing with an increase in items. Tasks which heavily burden the resource pool of working memory impose a high cognitive load while tasks which are automatic or processed with little effort impose a low cognitive load.

Several studies have found that cognitive load is an important variable to consider in spatial learning research. For example Deyzac, Logie and Denis (2006) tested the ability of participants to learn a spatial layout from a route and survey perspective in single and dual task conditions. The researchers found that participants who completed a concurrent spatial tapping task demonstrated less accurate recall of the spatial layout than participants in the single task group. These results provide an example of cognitive overload during spatial learning, in which a high load obstructed spatial encoding. As a second example, Garden et al. found that articulatory suppression and spatial tapping detrimentally affected route learning. As in Deyzac et al.'s investigation the authors did not compare active and passive participants, highlighting the need to examine the potential relationship between interactivity and cognitive load. Third, dual task studies have established that map learning is detrimentally affected by visuo-spatial interference (Coluccia, Bosco, & Brandimonte, 2007) and, to a lesser extent, verbal interference (Garden et al., 2002). Coluccia et al. (2007) had participants learn a map while conducting a simultaneous spatial tapping task or without interference. The researchers measured survey learning by having participants hand sketch the explored map from memory. It was found that participants in the spatial tapping group drew maps with inferior Euclidian properties (i.e., relative landmark locations) compared to those who studied the map without interference.

These findings point to the influence of working memory manipulations in map learning. It is critical to emphasize that the concept of cognitive load is relevant in a discussion of interactivity in spatial learning because active navigators process a greater number of simultaneous tasks relative to passive observers. For example, bus drivers navigate through traffic while physically controlling movement of the bus. In contrast, a passenger can focus their cognitive resources entirely on observing the environment.

However, studies of interactivity have found inconsistent results. Investigations in this area have employed a host of methodologies, examining real-world and laboratory spaces (e.g., von Sülpnagel & Steffens, 2012), virtual navigation (e.g., Wilson & Péruch, 2002), small-scale spaces (e.g., Sandamas & Foreman, 2014) and large-scale environments (e.g., Wallet, Sauzéon, Larrue, & N'Kaoua, 2013), making a direct comparison between studies difficult.

Some researchers have found that active learning is advantageous. Brooks, Attree, Rose, Clifford and Leadbetter (1999) observed an advantage associated with active control relative to passive observation. Active participants controlled exploration of a virtual environment by manipulating a joystick, whereas passive participants merely observed. Active learners recalled the spatial layout of the virtual environments with greater accuracy by comparison with passive participants. However, memory for objects found in the environment did not differ between active and passive groups. Several other investigations have reported a beneficial effect of activity in spatial learning (Chrastil & Warren, 2012, 2013; Foreman, Foreman, Cummings, & Owens, 1990; Hahm et al., 2007; Péruch, Vercher, & Gauthier, 1995; Tan, Gergle, Scupelli, & Pausch, 2006; von Sülpnagel & Steffens, 2012; Wallet et al., 2013).

Other research has found that activity was not beneficial. Several investigations reported no difference between active and passive learners (e.g., Foreman, Sandamas, & Newson, 2004; Wilson, 1999; Wilson, Foreman, Gillett, & Stanton, 1997) or a passive advantage (Experiment 1, Wilson & Péruch, 2002). For example Wilson et al. (1997) conducted an experiment comparing active and passive spatial learning in a simulated environment and found that activity did not produce an advantage in judgments of relative direction. A subsequent experiment (Wilson, 1999) investigated whether high attention in passive learners could account for the equivalence in performance. The results showed statistically equivalent accuracy in judgments of relative direction (while controlling for attention in the learning phase). The finding of no difference between active and passive groups is important given that traditional models of interactivity suggest that activity should result in superior spatial learning (Appleyard, 1970), whereas Wilson's et al. results reinforce the conclusion that activity is not always beneficial.

In the current experiment interactivity and cognitive load were manipulated between groups. Interactivity was manipulated by having the active participants control map navigation (only parts of the map could be viewed at any given point in time, and the active participants determined which part could be viewed) while yoked passive participants simply observed without being in control of the portions that were viewed. Cognitive load was manipulated by having half the participants learn the map without interference, whereas the other half performed a spatial tapping task (for a similar procedure see Farmer, Berman, & Fletcher, 1986; Smyth, Pearson, & Pendleton, 1988), thus increasing cognitive load. After the study phase was completed spatial knowledge was assessed by pointing (orientation) judgements and a map drawing task (for an example of similar pointing and drawing tasks see Waller, Loomis, & Steck, 2003).

We hypothesized an interaction between cognitive load (high versus low) and interactivity (active versus passive) in both dependent measures. Passive participants were expected to display an advantage relative to active participants in the high cognitive load condition. The hypothesis was based on the assumption that a high load disrupts efficient encoding for active learners who made decisions while simultaneously carrying out a spatial tapping task. Passive observers did not make viewing decisions and were thus expected to be less affected by an increase in load. Note that we expected little or no difference between active and passive participants in the low cognitive load condition as a low load was unlikely to exceed the processing limits of either active or passive learners.

Method

Participants

Sixty university students (37 females, 23 males), aged 17-52 with a mean age of 21, took part in the experiment.

Design

Four groups of participants were tested in a 2 X 2 design with activity type (active, passive) and cognitive load (low, high) as between-participants factors. Each group contained 15 randomly allocated experimental volunteers. The volunteers took part in two tasks: a “point to unseen target task” and a map drawing task. The former employed latencies and response errors as dependent measures and involved directional judgments, half of which were aligned with how the map was explored (facing north) and the other half were contra-aligned (facing south). In the map drawing task, participants drew the map they had studied by including the correct landmark locations and the spatial relationship between landmarks. The maps were analysed using ratings (scale 1-10).

Materials

An A3 sized map (297mm × 420mm) was presented to the students (Figure 1). The map was covered by a sheet of cardboard (621mm × 755mm) during the learning phase. To allow limited vision of the map, the cardboard had a 82×71mm diameter hole cut in the centre, which allowed participants to view approximately 5% of the map at a given moment. The cardboard also indicated the directions ‘North’, ‘South’, ‘East’, and ‘West’, with ‘North’ aligned with the top of the map. In the spatial tapping task, a 2×2 grid on an A4sized (210mm × 297mm) sheet of laminated paper was employed. The numbers 1-4 were printed in ascending order in a clockwise sequence in the four cells of the grid (for a similar procedure see Farmer, Berman, & Fletcher, 1986; Smyth, Pearson, & Pendleton, 1988).

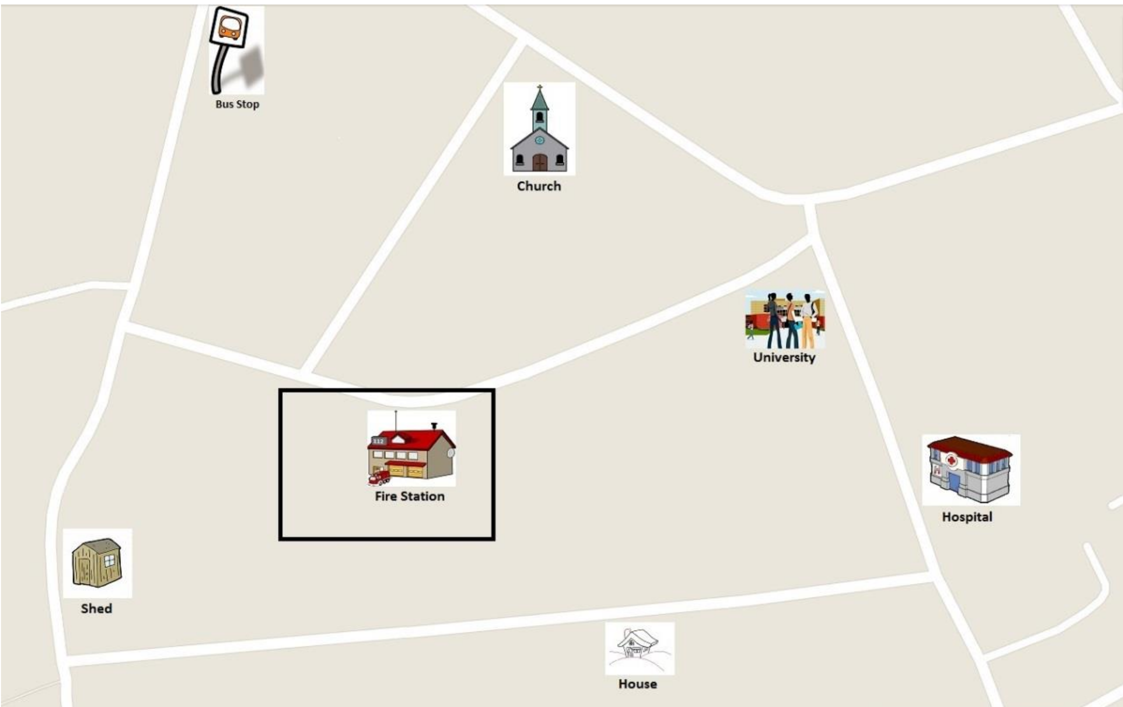

Figure 1. The map explored by participants during the learning phase. Note that the map was placed under a sheet of cardboard with a 82×71mm hole in the centre (relative size illustrated by the black rectangle).

A pointing device was used to assess participants' knowledge of landmark locations. 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). The time taken by participants to indicate the direction of an object was unobtrusively recorded using a hand-held 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 drawing of the map.

Procedure

The experiment was conducted in two stages: a study phase and a testing phase.

Study Phase

The 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 its centre. Active participants verbally instructed the experimenter to move the sheet of cardboard north, south, east or west, thus making different parts of the map visible through the hole in the cardboard. Yoked passive participants viewed the map simultaneously with the active navigator and were instructed to observe the areas exposed by the hole in the cardboard without communicating with the active participant. The experimenter sat between the active and passive participants. The sitting position of active and passive learners (left versus right relative to the experimenter) was counterbalanced. The experimental volunteers were asked to attend to the spatial relationship between the landmarks.

Those in the high load group performed the spatial tapping task concurrently while exploring the map, using their dominant index finger to tap the numbers 1-4 in ascending order in a clockwise sequence at the rate of one tap per second. The experimenter demonstrated the procedure to ensure understanding. Participants were instructed to focus their visual attention on the map, while completing spatial tapping to the best of their ability. Any substantial deviation in spatial tapping accuracy or consistency was pointed out by the experimenter. Participants had 2.5 minutes for map exploration (Thorndyke & Hayes-Roth, 1982).

Testing Phase

To initiate the testing phase, one student was asked to leave the laboratory while the other completed the pointing task. Following the procedure of Wilson and Péruch (2002), the student waiting outside was asked to rehearse the image of the map until their test began. The order of testing active and passive volunteers was counterbalanced. In the pointing task, spatial knowledge was assessed using a “point to unseen target task”. The experimental volunteers were asked to imagine standing at a landmark facing either north or south, while pointing toward another landmark with the pointing device. For example, they 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 paper. Their task was to draw the map (time limit: 1.5 minutes) 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). Students could not see each other's drawings during this part of the experiment, and they were asked to include a compass on their map. The maps were rated for accuracy using two methods: landmark placement errors and subjective ratings. Placement errors were calculated by measuring the distance between where participants placed landmarks and their true location. This was accomplished by overlaying a scale acetate image of the correct map onto the drawn maps and measuring landmark error with a ruler. Subjective ratings were obtained by two raters who evaluated the accuracy of drawn maps on a 1-10 scale, with higher scores indicating greater accuracy. Raters were instructed to make judgments on the basis of the relative spatial accuracy of the landmarks.

Results

Preliminary analyses (employing independent sample t-tests) were conducted on latencies and error scores in the pointing task to determine whether there was an order effect. The analyses revealed that test order had no effect on performance (all *p*s > .20). Consequently, the data for groups tested first and second were collapsed for the following analyses.

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 within-participants factor.

The analysis of absolute pointing errors revealed a significant main effect of alignment, $F(1, 56) = 24.09$, $p < .001$, *partial* $\eta^2 = .30$, indicating that participants answered aligned questions ($M = 51°$, $SD = 18°$) with greater accuracy than contra-aligned questions ($M = 70°$, $SD = 31°$). The main effect of activity type was also significant, $F(1, 56) = 4.08$, $p =$

.04, *partial* $\eta^2 = .07$, with passive participants demonstrating lower mean pointing error (*M* = 55°, *SD* = 20°) than active participants (*M* = 66°, *SD* = 20°). The effect of cognitive load was not statistically reliable, $F(1, 56) = .01$, $p = .98$. The interaction between cognitive load and activity type, $F(1, 56) = 2.99$, $p = .09$, *partial* $\eta^2 = .05$, approached significance and is presented in Figure 2. Performance was similar in the low load group (active *M* = 61°, *SD* = 21°; passive *M* = 60°, *SD* = 20°), whereas passive participants had numerically lower scores (*M* = 51°, *SD* = 19°) than active participants (*M* = 70°, *SD* = 18°) in the high load group. No other two or three-way interactions approached significance (*p*s > .05).

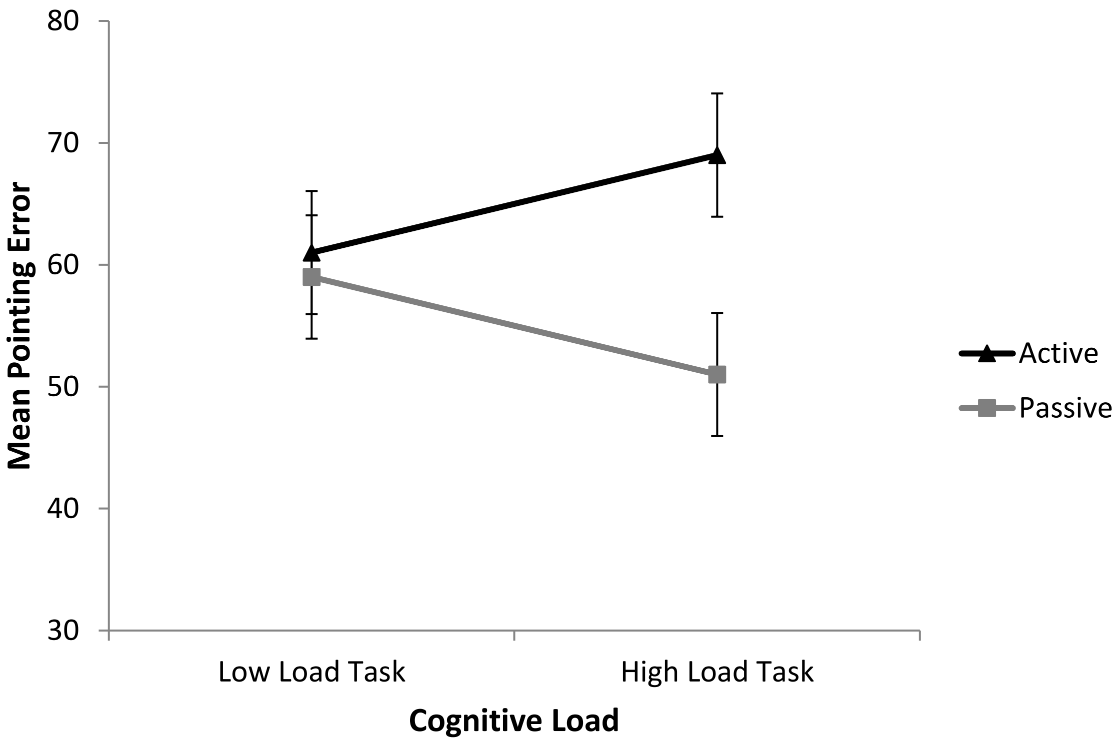

Figure 2. Analysis of mean absolute pointing errors from the pointing task as a function of activity type and cognitive load (±1 standard error of the mean).

The analysis of response latencies indicated a significant main effect of alignment, $F(1, 56) = 35.40$, $p < .001$, *partial* $\eta^2 = .39$. Participants were faster for aligned questions (*M* = 6.2 seconds, *SD* = 2.7 seconds) relative to contra-aligned questions (*M* = 8.3, *SD* = 3.4). The main effects of activity type, $F(1, 56) = 1.46$, $p = .23$, cognitive load, $F(1, 56) = .08$, $p = .78$, and the interaction between these variables $F(1, 56) = 2.10$, $p = .15$, were non-significant. Likewise, all other two and three-way interactions (for response latencies) were not significant (ps > .05).

Drawing task

Subjective ratings were obtained from two independent raters who evaluated the maps on a 1-10 scale, with higher scores indicating greater accuracy. The raters' evaluations demonstrated strong reliability, $r(58) = .74$, $p < .001$, and were averaged into a single mean evaluation score. A Kolmogorov-Smirnov test demonstrated that the ratings were normally distributed ($p > .05$).

For map drawings two ANOVAs with activity type (active, passive) and cognitive load (low, high) as factors were used to analyse subjective ratings and landmark placement errors. The analysis of ratings revealed that the main effects of activity type, $F(1, 56) = 3.09$, $p = .08$, and cognitive load, $F(1, 56) = 2.39$, $p = .13$, were not significant. However, the interaction between activity type and cognitive load was statistically reliable, $F(1, 56) = 5.71$, $p = .02$, *partial* $\eta^2 = .09$. The interaction is illustrated in Figure 3. Simple main effect analyses (with Bonferroni correction) demonstrated that there was no effect of activity type in the low cognitive load group ($p = .69$), whereas in the high cognitive load group, passive participants' map drawings were rated as more accurate ($p = .005$) than those from active participants.

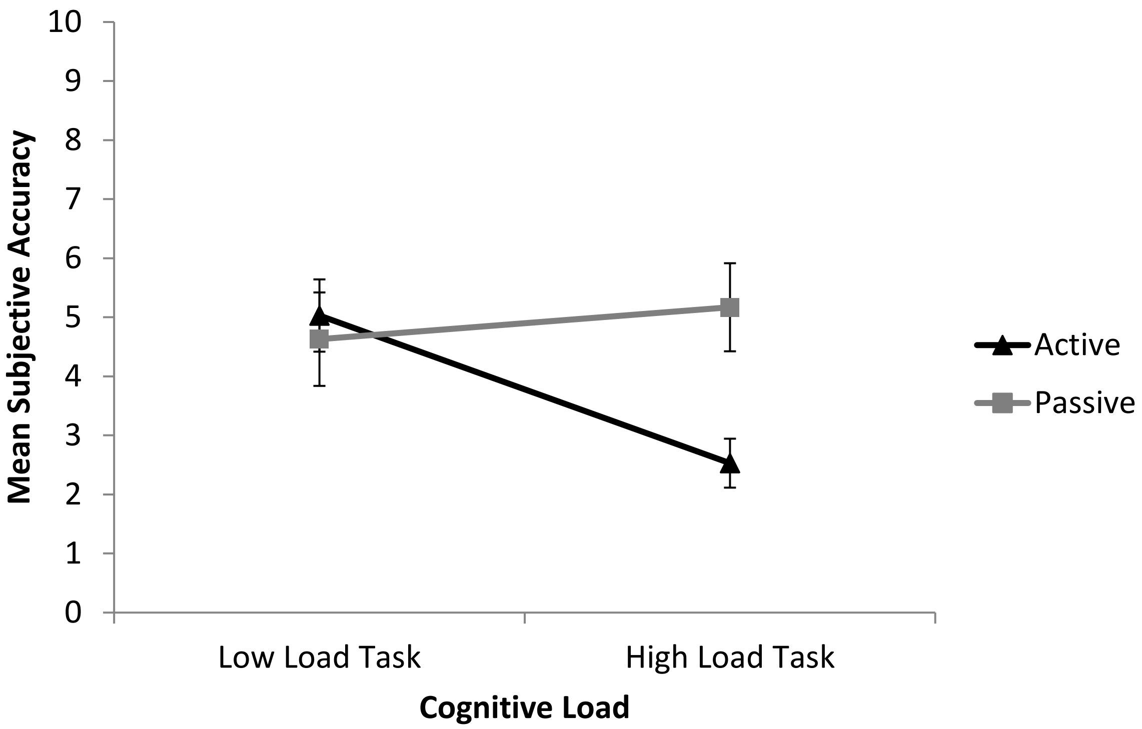

Figure 3. Analysis of mean subjective accuracy ratings in the map drawing task as a function of activity type and cognitive load (±1 standard error of the mean).

For landmark placement errors significant main effects of activity type, $F(1, 56) = 10.66$, $p = .002$, *partial* $\eta^2 = .16$, and cognitive load $F(1, 56) = 8.28$, $p = .006$, *partial* $\eta^2 = .13$, were found. Passive participants drew maps more accurately ($M = 48.50$, $SD = 16.26$) than active participants ($M = 61.84$, $SD = 18.89$), and low cognitive load participants ($M = 49.29$, $SD = 15.17$) outperformed high cognitive load participants ($M = 61.05$, $SD = 20.27$). The interaction between activity type and cognitive load was also significant, $F(1, 56) = 7.55$, $p = .008$, *partial* $\eta^2 = .12$. Simple main effect tests showed that activity type had no effect in the low cognitive load group ($p = .716$), whereas in the high cognitive load group passive participants drew maps more accurately than active participants ($p < .001$). The interaction is presented in Figure 4.

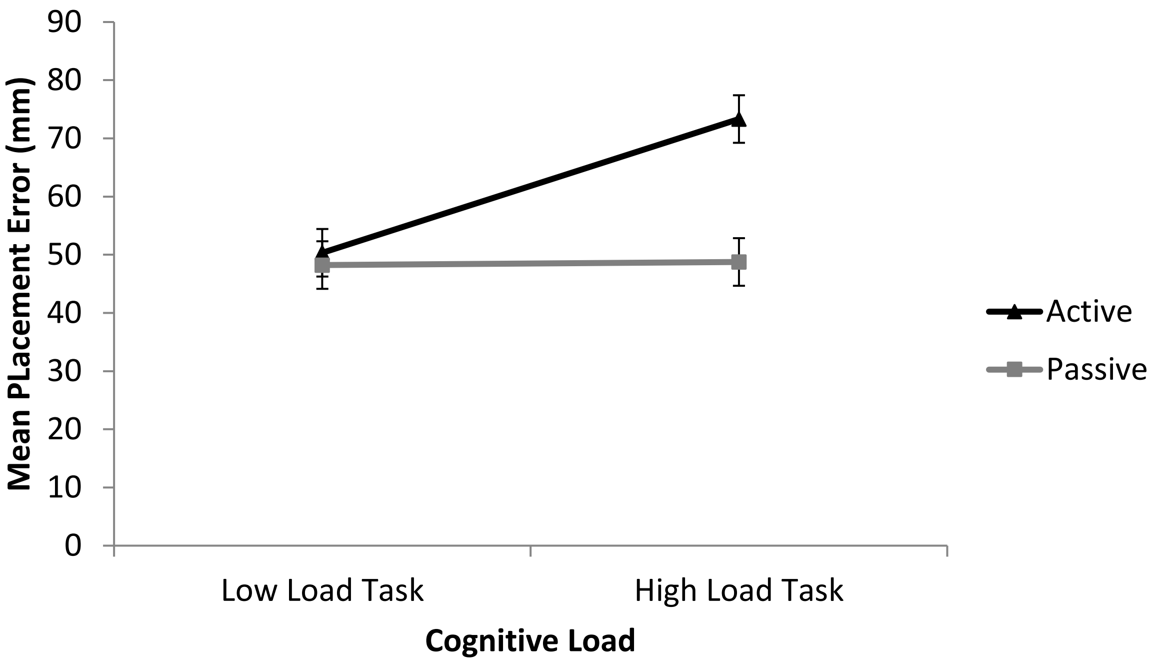

Figure 4. Analysis of mean landmark placement errors (in mm) in the map drawing task as a function of activity type and cognitive load (±1 standard error of the mean).

Discussion

Active and passive participants studied a map either while performing a simultaneous spatial tapping task (high cognitive load) or in the absence of this task (low cognitive load). Pointing and map drawing tasks provided measures of spatial recall as a function of learning. In the pointing task, passive participants were found to make directional judgements to landmarks more accurately than active participants, an advantage which was numerically (but not significantly) apparent in the high load but not in the low load group. Reaction times for the pointing task were unaffected by cognitive load and interactivity, demonstrating that no speed/accuracy trade-off occurred.

The map drawing task revealed a similar pattern of results. For the ratings neither the main effect of activity type nor the effect of cognitive load was significant. However, the significant interaction between activity type and cognitive load indicated that map drawing was detrimentally affected by a high load for active participants, but not for passive participants. A similar interaction was observed for mean landmark placement errors, revealing that only active participants were detrimentally affected by a high load. The pattern of results observed in the two-way interactions (evident in map ratings and map landmark placement errors) is consistent with the assumption that when maps are studied activity can be detrimental to spatial learning. This suggests that active control of map exploration consumed greater mental resources than passive observation, with spatial tapping increasing task demands to the point that active participants found it difficult to accurately encode the map. Passive participants appeared to be able to handle an increase in cognitive load.

Both the pointing and drawing tasks demonstrated the same relationship between interactivity and cognitive load, albeit the interaction was only marginally significant for pointing errors. The pointing task focused on orientation and relied on egocentric perspective-judgment accuracy while, in contrast, the map drawing task evaluated an allocentric 'bird's eye view' perspective of the environment. The results suggest that both perspective-judgments and allocentric survey knowledge benefit from passive observation if cognitive load is high.

Our results do not support the notion that active learning is beneficial to spatial knowledge acquisition (e.g., Péruch et al., 1995; Wallet et al., 2013). Passive (rather than active) participants were able to manage an increase in cognitive load. It is possible that simple tasks (with a low load) are not able to detect potential differences between active and passive learners due to the greater availability of mental resources to deal with the encoding of spatial information. In contrast, demanding conditions may reveal an advantage of passive observation.

The current paper indicates that spatial tapping can affect map learning by raising cognitive demand. However the effect of other modalities of interference (e.g., verbal, executive) on interactivity in map learning are currently undetermined. Meilinger, Knauff and Bülthoff (2008) tested participants in a virtual navigation task with a concurrent visual or spatial interference task, a verbal interference task or no interference. All modalities of interference reduced wayfinding performance, suggesting that visual spatial and verbal memory is used in wayfinding. Ongoing work in our laboratory examines whether other types of task (e.g., verbal interference) also have an effect on map learning.

Our findings could help explain unexpected findings in other experimental paradigms investigating the difference between active and passive spatial learning. For example, Henkel (2013) investigated visuo-spatial memory for objects in a museum. It was found that objects which were (passively) viewed were remembered with greater accuracy than objects which were (actively) photographed. The author concluded that photographing an object made participants dismiss the object from memory. The present results provide an additional explanation for the photo-taking impairment effect, as manipulating a camera to take photos of objects presumably utilises more mental resources than observing the same objects.

This study focused on map learning, whereas interactivity has primarily been studied employing simulated movement in virtual environments or relying on real world navigation (Péruch & Wilson, 2004). We cannot be certain as to whether our results apply to spatial stimuli other than maps, as physical and motor feedback could play a role in spatial knowledge acquisition. Whether spatial knowledge is acquired from maps or through navigation has been shown to have an effect on the recall of the studied environment (Münzer et al., 2006; Thorndyke & Hayes-Roth, 1982; Wallet et al., 2013). Wallet et al.

observed that active navigation was primarily beneficial for ground-level navigation by comparison with an aerial perspective. It is thus possible that our conclusions regarding active and passive participants for high and low cognitive load tasks may differ for other forms of knowledge acquisition.

The notion that active learning can affect spatial knowledge acquisition in cognitively demanding tasks has been suggested in the context of virtual navigation studies. Sandamas and Foreman (2014; see also Sandamas & Foreman, 2015) reported findings consistent with the hypothesis that using an input device (e.g., a joystick or keyboard) in a virtual environment can increase cognitive demands and may compete for cognitive capacity in working memory, making it difficult to find differences between active and passive participants in computer-simulated environments. While we did not employ an input device here, it may be argued that in this study, active learners were affected by giving verbal directions to the experimenter during the learning phase. In other words, the verbalisations may have increased their cognitive load. The present design does not allow us to distinguish between the potential effects of decision making and verbalisations, although it is also possible that verbal activity reinforced spatial learning in active participants, as active behaviours are traditionally considered beneficial (Waller, Loomis, & Haun, 2004).

A final point to be considered concerns the observed differences between the two types of directional judgement tested. The analysis of pointing performance indicated that participants were better at aligned questions than contra-aligned questions. This finding is in agreement with the literature (e.g., Sholl, 1987; Tlauka, 2006) and presumably reflects differences in the difficulty of processing aligned and contra-aligned judgements. Contra-aligned judgements involve adoption of a novel viewpoint whereas aligned judgements were in the same orientation in which the map had been learned. The alignment effect did not interact with any other variable, indicating that the difficulty of processing contra-aligned judgments was similar for active and passive participants.

In summary, the present research provides evidence for a complex and context dependent relationship between interactivity and cognitive load. The results are consistent with the assumption that active spatial learning requires greater mental resources by comparison with passive observation and may therefore be detrimentally affected by high cognitive demands. Future research may focus on identifying the specific contextual relationships between interactivity and spatial learning.

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