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RESEARCH ARTICLE

No environmental context-dependent effect, but interference, of physical activity on object location memory

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Abstract
Research on context-dependent memory has addressed many external and internal types of contexts. However, whether the physical activity engaged in at the time of encoding and recall can act as an environmental context cue has been systematically investigated only in one study. The purpose of the present study was to replicate this; furthermore, given the effect of physical activity/effort on the way space is represented, we sought to extend the findings to object location memory. Using a 1-list paradigm (Experiment 1) and a 2-list paradigm (Experiment 2), participants had to learn the locations of objects on a grid and then recall them, while standing or walking on a health walker. No evidence of activity context effects was found. However, an interference effect of the motor task on location memory was detected, such that participants' performance was worse when walking, compared to standing, at encoding (Experiment 2) or recall (Experiment 1). Results are discussed based on the outshining hypothesis and the possible link between motor task and object location memory.

Keywords Object location memory · Spatial memory · Environmental context-dependent memory · Interference · Physical activity

Introduction

Environmental context-dependent memory refers to an increased memory for learned material when the environment or situation is the same at both the time of learning and the time of recall (Bjork and Richardson-Klavehn 1989; Pan 1926; Smith 1988). One of the first explorations of this effect came from teaching rats to run a maze and then rotating the maze to see whether this change in environment orientation would affect the rat's ability (Watson 1907). Albeit irrelevant for the task, changing the orientation context impaired rats' memory, as evidenced by an increase in the time it took and the errors committed to complete the maze.

Context-dependent memory has since been studied using a variety of different contexts. Among a host of possible cues, an advantage for reinstating a matching context at recall with that of encoding has been shown using different semantic contexts (Buschke and Lenon 1969; Light and Carter-Sobell 1970), process contexts (Falkenberg 1972), environmental contexts (e.g., rooms: Smith 1979; odors: Schab 1990; music: Smith 1985; for a review, see Smith 2013), and internal, psychophysiological states (e.g., mood states: Bartlett and Santrock 1979; Lang et al. 2001; for a review of state-dependent memory induced by psychoactive drugs, see Eich 1980). Importantly, it is not the effect of familiarity that increases memory recall for the matching context, as this factor is taken into account by, for example, giving similar exposure to the non-matching context (e.g., Rutherford 2000; Smith 1979).

Environmental context-dependent memory effects do not just occur in the laboratory. The effect has also been found in natural settings. In one of the best-known studies, participants were asked to learn a list of words while underwater or on dry land. When tested, recall was higher if it occurred in the matching environment (Godden and Baddeley 1975). Environmental context-dependent memory has been applied to live academic settings as well. In one such study, college students were given the choice to take their scheduled final examination in either their course lecture room with their course peers, or to take their final examination in a separate room with students from other courses. Students from nine different majors participated, and they were found to have higher scores, by approximately one grade increment,

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on their final examinations when taken in their course lecture room (Van Der Wege and Barry 2008). This finding exemplifies the relevance of the topic to everyday life and education. Similar results have been reported by Abernethy (1940), Eich (1985), Jensen et al. (1971), Metzger et al. (1979), Smith (1979), and Smith et al. (1978).

Another important application of environmental context-dependent memory is in eyewitness testimony. Smith and Vela (1992) tested the hypothesis that when eyewitnesses return to the "scene of the crime," they can use environmental context reinstatement to help recall memories of the event and increase positive eyewitness facial recognition. Participants viewed a staged event in a classroom and were later asked to identify the perpetrator in a photograph lineup of ten individuals. Participants were either asked to identify the perpetrator in the room in which the event occurred, or in a different room. Those who were tested in a different room either were given no instructions or were instructed to mentally reinstate themselves into the event room by imagining the environment. Results found that returning individuals to the room where the event took place increased positive eyewitness facial recognition compared to those tested in a different room. However, findings did not show any added benefits for instructing participants to mentally reinstate themselves into the event room.

Physical activity as a context

Although a large body of evidence has been accumulated using the environment and external stimuli as contexts, there is surprisingly scarce literature on whether what we do in the environment—i.e., the physical activity one is engaged in—at the time of encoding and recall can be used as context cue to improve memory retrieval. In a study by Miles and Hardman (1998), participants were asked to learn lists of words while either at rest or performing aerobic exercises via an exercise bicycle. Participants in the exercise condition were required to reach and sustain a heart rate between 120 and 150 bpm. Four separate word lists consisting of 36 three-syllabic words were used during encoding. All participants came to the laboratory for 4 days in a row, in which they completed each of the four possible conditions given by the factorial combination of the activity at encoding and retrieval (rest–exercise, rest–rest, exercise–rest, and exercise–exercise). Recall was significantly higher when the activity performed, and the associated heart rate, were matching.

Other relevant studies were completed by Clark et al. (1983) and Schramke and Bauer (1997). In both cases, participants were asked to either engage in exercise or rest before learning a list of words, and then, they had to complete the matching or opposite activity before recall. It was found that, when doing the matching activity, recall was significantly higher. However, unlike Miles and Hardman (1998), in those two studies participants engaged in exercise *before* encoding and recall phases rather than during. Therefore, the physical activity is not a context; rather, it is just used to alter the physiological arousal. In other words, those studies manipulated arousal as a context rather than physical activity.

Besides Miles and Hardman's study (1998), to the best of our knowledge, the only other relevant evidence of context effects of physical activity on memory comes from studies examining gum chewing. Baker et al. (2004) first showed that participants chewing gum (or not) consistently at learning and testing had higher rates of recall, supporting the idea that gum chewing is a sufficient context cue. Although similar findings have been reported (Miles et al. 2008; Rickman et al. 2013; Stephens and Tunney 2004), other studies have not been able to replicate these results (Anderson et al. 2005; Johnson and Miles 2008; Miles and Johnson 2007). The discrepancy in these findings has been attributed to differences in the types of memory tests being used at recall (immediate vs. delayed recall; short-term memory vs. long-term episodic memory) (Miles et al. 2008). Furthermore, it is still unclear whether it is the act of chewing gum, or the associated taste of the gum, that may serve as the context cue (Johnson and Miles 2008).

In sum, it is safe to say that there is very little research on context effects of physical activity. Furthermore, because the effect of chewing gum has been disputed, to the best of our knowledge, the issues have been addressed systematically only in one previous study (Miles and Hardman 1998). The purpose of the present study was to replicate this.

Physical activity/effort and the representation of space

Within the perspective of embodied cognition (Wilson 2002), considerable evidence suggests that physical activity/effort (potential for action) affects the way space is represented (Witt et al. 2010). For example, in studies examining the perception of space while wearing a heavy backpack (more effortful) or not (less effortful), it was found that participants who wore the backpack judged distances to be greater (Proffitt et al. 2003) and hills to be steeper (Bhalla and Proffitt 1999). In a second experiment completed by Proffitt et al. (2003), participants were asked to give a verbal estimate of distance to a target before and after walking on a treadmill. While on the treadmill, participants wore a headgear displaying a virtual world that either moved at the same speed as the treadmill or was motionless. Participants who experienced a motionless virtual world estimated the target distance to be greater than it was. The authors' interpretation was that those who experienced zero optic flow felt they had to exert more effort to walk to the target, and this was associated with overestimation of distances. Analogous findings were previously obtained by Rieser et al. (1995). Participants had to walk on a treadmill that was placed on a trailer and pulled by a tractor. When tested in a task in which they had to walk blindfolded to a target, participants who walked on a treadmill that was going faster than the speed of the tractor blind-walked past the targets, while participants who walked on a treadmill that went slower than the tractor blind-walked short of the targets.

Besides the effect of physical effort on the perception of space, there is also some evidence of its effect on *memory* of space. In the real world, the amount of energy used to traverse a path is generally proportional to the distance traveled. Research suggests that, when more energy or effort is required to travel a distance, this tends to be overestimated in memory. In Cohen et al. (1978), participants were asked to judge the distance traversed on a path. Those who walked routes that contained slopes or environmental barriers tended to overestimate remembered distances compared to participants who walked routes without slopes or environmental barriers. Similar results were reported by Okabe et al. (1986). Participants walked several routes in a large environment. When asked to make estimates from memory, they tended to overestimate the distance of routes they walked that were sloped (both uphill and downhill), compared to routes that were flat.

In sum, there is a link between physical activity/effort and the way space is represented. However, to the best of our knowledge, there is only scarce literature on physical activity as a context cue for memory in general, and no previous study specifically testing context effects on spatial memory.

The present study

The present study sought to replicate Miles and Hardman (1998), but using a spatial memory task rather than a more common word-list recall task. The goal was to determine whether physical activity can act as a context cue for object location memory.

Object location memory is the ability to recall the location of an encoded object, and it is distinct from recalling the identity of the object. It was tested with the classic paradigm introduced by Silverman and Eals (1992). The task required participants to encode the location of objects presented on a grid; then, at recall, when presented with each object one at a time, they had to recall their location on an empty grid. Remembering where an object is located or an event occurred is a crucial skill for everyday life (where are your car keys?); furthermore, it is an aspect of episodic memory that, to the best of our knowledge, has received no attention in context-dependent memory research.

Two experiments were carried out, both trying to answer the same question, but with different designs: one using a 1-list paradigm (Experiment 1) and the other using a 2-list paradigm (Experiment 2). In a 1-list paradigm, participants learn one list of items while being exposed to the context cue; then, at recall, the context is either reinstated (matching context) or not. It is expected that participants who recall in the reinstated context condition will perform better. For example, Smith et al. (1978) found higher rates of recall for participants who studied a list of words in the same room that they were later tested in, compared to participants who studied and recalled the list of words in non-matching rooms. Conversely, in a 2-list paradigm, participants learn two different lists of items, each one with a different context. At test, only one context is reinstated, and it is expected that the items from the list learned with the reinstated context will be recalled better than those learned with the non-reinstated context. For example, participants were asked to learn a list of words in room A, and then, a second list of words was learned in room B. Participants then freely recalled both lists of words in either room A, room B, or in a neutral room. Recall was best for the lists of words that were learned and recalled in matching room (Smith et al. 1978). The advantage of a 1-list paradigm is that it is a faster procedure, suitable for an exploratory study, whereas the advantage of a 2-list paradigm is that it is a within-subject design and thus has less subject variability and more statistical power. By using both designs, we sought to find converging evidence in support of activity context effects on object location memory.

Experiment 1

Participants had to learn the location of 28 objects presented on a grid; meanwhile, they were either walking or standing on a health walker. The health walker was chosen because it enabled a movement pattern (walking) that is simple, routine, and does not require unfamiliar balance coordination. After learning the location of the 28 objects, participants completed a distractor task while engaged in the opposite activity of encoding. At recall, participants were presented with an object at a time, and they had to estimate its location on an empty grid while either walking or standing. Basically, participants were randomly assigned to a condition given by the factorial combination of the physical activity engaged in at encoding (walking or standing) and at retrieval (walking or standing). The hypothesis was that there would be a significant interaction between the two factors, such that recall would be higher when the activity at recall matched the one at encoding.

Method

Participants

A total of 44 participants were collected (40 females and 4 males) among undergraduate students enrolled in the Introductory Psychology participation pool. Participants were recruited through the SONA online registration system and received course credit in compensation. Female and male participants were randomly assigned to one of the four conditions (10 females and 1 male per condition) given by the factorial combination of the activity at encoding and recall: walk–walk, stand–stand, walk–stand, and stand–walk.

Materials

Two stimulus grids were prepared. The first consisted of a 51 × 76 cm poster board with a 7 × 4 grid, creating 28 boxes containing an object (see Fig. 1). The 28 objects were adapted from a stimulus array created by Silverman and Eels (1992). The second grid was similar but blank, i.e., the objects inside the 28 boxes, had been replaced with a number (1–28).

A XS2000 Logic System Health Walker was used for participants to stand or walk on (see Fig. 2). The health walker was positioned in the center of the room. The room was 8.7 m long × 4.2 m wide and 3.6 m tall. The health walker was located 85 cm away from the poster board, and the bottom of the poster board was 145 cm from the ground.

Participants' heart rates were measured using a Santa Medical Finger Pulse Oximeter model SM-165.

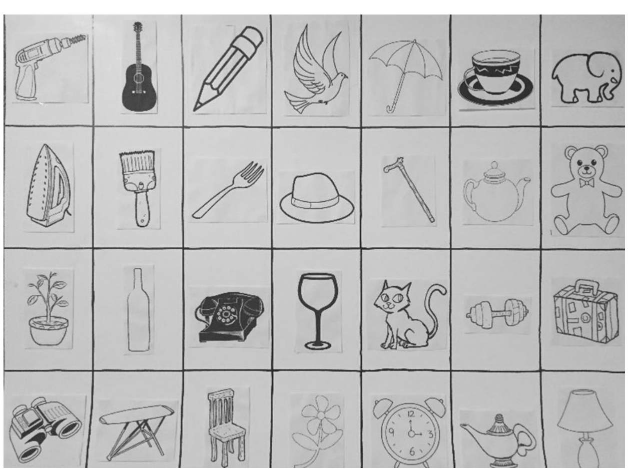

Fig. 1 Picture of the 28-object grid used in Experiment 1. (51 × 76 cm poster board)

Fig. 2 Picture of the experimental setup and the XS2000 Logic System Health Walker used in both Experiments 1 and 2. (Figure is obtained with consent from the individual portrayed)

Procedure

The study was approved by the Eastern Illinois University Institutional Review Board for research on human subjects. All participants were tested individually. Informed consent was obtained from all individual participants included in the study. They were told in advance that the purpose of the study was to discover how people remember objects in space. They were informed that they would be asked to either walk or stand on the health walker while studying a grid containing 28 objects and that then they would be asked to recall the locations of the objects. To familiarize participants with the health walker, they were provided a demonstration of how to walk and stand on the health walker, and they were given time to practice and become comfortable with those activities.

Experiment 1 consisted of three phases: encoding (also referred to as learning), delay (with the distractor task in the middle), and recall (also referred to as testing). The physical activity during encoding and recall was determined by the assigned condition; the activity during the distractor task (in the delay phase) was always opposite to that during encoding. When walking on the health walker, they were asked to follow whatever pace they felt comfortable with.

Encoding phase

Participants stepped on the health walker, and when ready, they were told to stand or walk, depending on the condition. After 5 s, the grid with 28 objects was presented (see Fig. 1). They had 90 s to study it. After this, the grid was removed and they could step off the health walker and rest while sitting.

Delay phase

The delay phase lasted a total of 210 s, composed of a 60 s pause (participants rested while sitting), followed by a 90 s distractor task, and then another 60 s pause (participants rested while sitting). During the distractor task, participants engaged in either walking or standing on the health walker. (The activity was always opposite what they did during the encoding phase.) At the same time, they had to count aloud backwards from 200 by three's. The purpose of the distractor task was to prevent participants from continuing to rehearse the object locations. More importantly, it provided exposure to the physical activity context that participants had not experienced during encoding. Giving all participants the same amount of exposure to the two physical activity contexts ensured that a potential activity context effect could not be explained by unfamiliarity with the physical activity in the non-matching conditions.

Recall

Participants engaged in the assigned physical activity and were presented with a blank grid. In place of the objects, each grid box had been labeled with a number. The experimenter, standing next to the right side of the grid, showed one by one each object's individual picture and verbally stated its name; the order of the objects was pseudorandom, and the same for all participants. For each object, participants were instructed to tell the experimenter where it had been located during encoding by verbally stating the corresponding grid number. Each picture was held approximately 25 cm away from the middle of the right side of the blank grid; the picture was held in that position until the participant stated the recalled location. No feedback was provided, and the pictures were not placed on the grid. The recall phase was not timed; participants were instructed to take as much time as they needed.

Participant's pulse rates were taken four times during the experimental session. Pulse rates were measured while sitting after signing the consent form, and after stepping off the health walker following encoding, the distractor task, and recall.

Overall, the whole experimental session lasted approximately 20 min.

Data analysis

The recall score was calculated assigning 1 to every object recalled in the correct box, and 0 for every object recalled in the incorrect box. This scoring is referred to as hit/miss scoring, and the overall recall score for each participant could vary between 28 (perfect score) and 0.

Table 1 Summary table for Experiment 1 hit/miss scoring

Activity during encoding	Activity during recall	*M*	SD	*N*
Walk	Walk	6.73	3.74	11
	Stand	9.82	3.91	11
Stand	Walk	7.73	2.24	11
	Stand	11.73	5.62	11

Means and standard deviations for the recall score, calculated using the hit/miss scoring method, in each of the conditions. The score ranged from 0 to 28 (perfect score)

Table 2 Summary table for Experiment 1 distance scoring

Activity during encoding	Activity during recall	*M*	SD	*N*
Walk	Walk	−47.14	16.80	7
	Stand	−37.57	15.91	7
Stand	Walk	−36.00	8.52	7
	Stand	−30.71	9.46	7

Means and standard deviations for the recall score, calculated using the distance scoring method, in each of the conditions. The score ranged from −168 to 0 (perfect score)

Ideally, instead of treating all errors equally (as in the hit/miss scoring), we would have preferred to use a recall score that took into account the distance between the recalled box and the correct box. With distance scoring, a correct response (recalling an object in the correct box) was coded as 0 points, while incorrect responses were given a score between −1 (one box away) and −6 (six boxes away). The overall score for each participant was the sum of the distance scores for each object: this could range from 0 (perfect score) to −168. This scoring provides a more sensitive measure of memory recall because it is graded. (Errors are weighted proportionally to the distance from the correct location.) However, because the exact recalled box was accidentally not recorded for some participants, we were able to apply distance scoring only to a subset of the sample ($N = 28$). Therefore, for Experiment 1, the primary DV was the hit/miss scoring, and the distance scoring is reported only for completeness.

The recall score was submitted to a 2 (physical activity at encoding: walking or standing) × 2 (physical activity at retrieval: walking or standing) between-subjects factorial ANOVA. An activity context effect would lead to a significant interaction (greater recall with matching activities at encoding and recall) (Tables 1, 2).

Gender was not considered as a factor in the analyses because of the extremely small number of men in the sample. Male participants were spread equally among the conditions.

Results

Using the hit/miss scoring on the whole sample ($N = 44$), the 2 (physical activity at encoding) × 2 (physical activity at retrieval) between-subjects factorial ANOVA revealed no main effect of encoding activity, $F(1, 40) = 1.41$, $MSE = 16.51$, $p = .242$, $\omega_p^2 = .01$, but a significant main effect of recall activity, $F(1, 40) = 8.38$, $MSE = 16.51$, $p = .006$, $\omega_p^2 = .14$ (see Fig. 3). Participants recalled significantly more locations when standing than walking at recall. Crucially, there was no significant interaction between the activity during encoding and recall, $F(1, 40) = .14$, $MSE = 16.51$, $p = .713$, $\omega_p^2 = .00$.

When applying the distance scoring for a subset of the participants ($N = 28$), there was no significant main effect of encoding activity, $F(1, 24) = 3.25$, $MSE = 174.42$, $p = .084$, $\omega_p^2 = .07$, recall activity, $F(1, 24) = 2.22$, $MSE = 174.42$, $p = .150$, $\omega_p^2 = .04$, and no significant interaction, $F(1, 24) = .18$, $MSE = 174.42$, $p = .672$, $\omega_p^2 = .00$.

A one-way repeated-measures ANOVA was conducted on the heart rates of participants at 3 points in time: at rest after signing the consent form, after the first time they stood on the health walker, and after the first time they walked on the health walker. There was a significant difference in the heart rates of participants across the three different levels, $F(2, 86) = 29.69$, $MSE = 83.22$, $p < .001$, $\omega^2 = .16$. Pairwise comparisons with Sidak correction showed that the heart rates of participants after consent ($M = 86.75$, $SD = 16.67$) were significantly lower compared to the heart rates of participants after standing ($M = 97.64$, $SD = 15.87$) ($p < .001$) and after walking ($M = 101.11$, $SD = 16.67$) ($p < .001$). However, the heart rates of participants after standing and after walking were not significantly different from one another ($p = .207$).

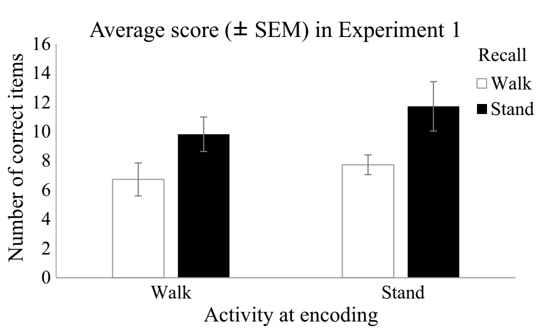

Fig. 3 Average (± SEM) number of correct object locations recalled for encoding activity and recall activity in Experiment 1 (hit/miss scoring). There was a significant main effect of the activity at recall

Discussion

Both using the hit/miss scoring and the distance scoring (albeit only for a subset of the sample), results did not support the hypothesized activity context effect on object location memory, which would have predicted a significant interaction between activity at encoding and that at retrieval. We identified three reasons why we might have failed to find a significant activity context effect.

First, we considered that our experiment might have had low sensitivity. The literature suggests that, when context effects are not detected, this might be related to the memory paradigm used (Smith 1994). For example, context effects tend to be found more consistently when using a 2-list, within-subjects design (Smith 1988; Smith and Vela 1992). As previously mentioned, a basic 1-list design (like the one in Experiment 1) uses a between-subjects design where each participant learns in only one context and at recall the context is either reinstated or not. However, in a 2-list paradigm, a within-subject design is used, where each participant learns in two contexts, and at recall only one of the contexts is reinstated. The use of a within-subjects design leads to less subject variability and more statistical power. Therefore, we reasoned that a 2-list design might be more sensitive for addressing our research question.

Second, another factor that has been proposed to affect the presence of context effects is the cue-overload effect. The cue-overload effect, also referred to as fan effect, describes this phenomenon: as more memory targets become associated with the same cue, the less likely that cue will sufficiently evoke recall of the targets (Smith 2013). For example, Rutherford (2004) examined environmental context-dependent memory by presenting to-be-remembered items superimposed over a background color. In one condition, all items were shown superimposed over the same background color. In a second condition, items were superimposed over one of three different background colors. No environmental context effect was found for the one-background color condition (higher cue overload), whereas a significant context effect was found for the three-background color condition (lower cue overload). Similar results were found in a study completed by Smith and Manzano (2010). In Experiment 1, failure to find a significant activity context effect may be due to too many memory targets (28 object locations) being associated with the same cue (walking or standing). An overloaded context cue might have failed to elicit retrieval of the object locations. For this reason, we thought that having fewer object locations associated with each context would increase our chances of detecting an activity context effect.

Third, Experiment 1 revealed a significant main effect of physical activity on memory retrieval: participants recalled more correct locations when standing than when walking at recall. This resembles a motor interference effect in which the more demanding physical activity (walking on the health walker) competes for cognitive resources with memory retrieval more so than the less demanding physical activity (standing). Similar results were found in studies completed by Darling and Helton (2014), Lambourne and Tomporowski (2010) and Yogev-Seligmann et al. (2010). This interference effect will be addressed in the general discussion, but here we wish to point out that it might have washed away a possible activity context effect. Therefore, we reasoned that we would be better able to address our question if we decreased the interference effect.

In sum, Experiment 1 did not find context effects of physical activity on object location memory. We identified three main possible limitations, and in order to be more thorough, Experiment 2 was carried out taking these into account.

Experiment 2

Experiment 2 replicated Experiment 1 and, again, tested for an activity context-dependent effect on object location memory, but with three major improvements.

First, in an attempt to increase the sensitivity of our research design, we used a 2-list within-subject paradigm instead of a 1-list paradigm. Participants had to encode a first grid of object locations while either walking or standing; then, they learned a second grid of object locations while doing the opposite physical activity. Finally, they had to recall all the object locations while doing only one of these physical activities. This entails that, for each participant, one context is reinstated at recall and the other is not reinstated. Activity context-dependent memory would be supported by greater recall of the object locations learned in the reinstated context (e.g., when participant are walking at recall, they should have greater retrieval for object locations learned while walking than while standing); this was the hypothesized outcome.

Second, compared to Experiment 1, we decreased the number of memory targets associated with each context cue. Now participants learned only 14 object locations per context, as opposed to 28. This was carried out to diminish the cue-overload/fan effect, thus potentially increasing the strength of each context as retrieval cue.

Third, we attempted to decrease motor interference effects on memory recall by increasing participants' familiarity with the physical activities. The experimental procedure now required participants to start walking (or standing) for 30 s before the grid would be presented; this was considered enough time to allow them to carry out the walking activity automatically before focusing on encoding the stimuli. More importantly, after the encoding of the stimuli, a rehearsal procedure was carried out in which they had to practice recalling the stimuli, meanwhile continuing to engage in the physical activity; the goal was to render walking on the health walker less cognitively demanding and at the same time increase the association between activity context and target object locations.

Method

Participants and design

A total of 32 new participants were collected (24 females and 8 males). Participants had to learn a first grid of object locations (grid A or B) while walking or standing, then a second grid while doing the opposite activity. At recall, half of the participants had to recall all the object locations for both grids while walking, and the other half while standing. Therefore, for each participant, one physical activity context is reinstated at recall and the other is not reinstated. Both female and male participants were randomly assigned to one of the 2 conditions (16 participants per condition, 12 females and 4 males) determined by the activity reinstated at recall (walking or standing). The first grid encoded (A or B) and the first physical activity engaged in (walking or standing) were counterbalanced across conditions. The dependent variable was the memory recall for object locations from the grid learned while walking and standing. The overall design was a 2×2 mixed factorial, with the physical activity at recall (walking or standing) being the between-subjects factor, and the grid learned (while walking and standing) the within-subject factor.

Materials

Same materials were used as in Experiment 1, except that two different stimulus grids were prepared (same dimensions as in Experiment 1). Grids A and B contained 14 objects each, and in each grid, they were positioned leaving an empty box in between (see Fig. 4); the objects in grids A and B were located in complementary, non-overlapping boxes.

Procedure

The study was approved by the Eastern Illinois University Institutional Review Board for research on human subjects. Participants were tested individually. Informed consent was obtained from all individual participants included in the study. Upon participant's arrival, they were given a 5-min "cooldown" period to allow their heart rate to fall to resting. During this "cooldown" period, participants sat on a chair and were informed that the purpose of the study was

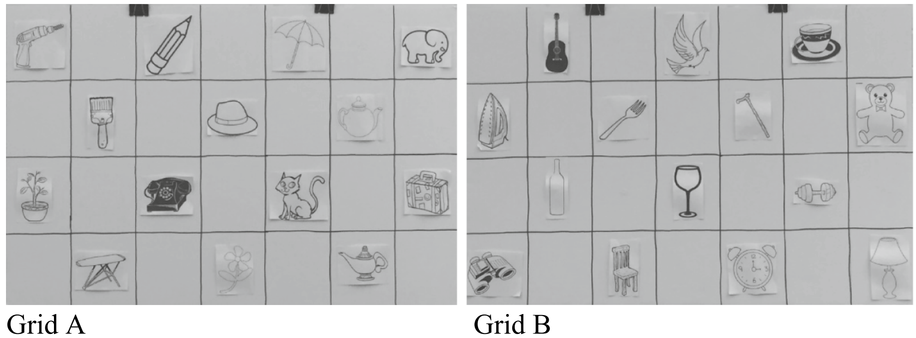

Fig. 4 Picture of Grid A and Grid B used in Experiment 2

to discover how people remember objects in space. They were told that they would, at different points, be asked to either walk or stand on the health walker while studying a grid containing a variety of objects. They were informed that they would later be asked to recall the locations of the objects. After concluding the 5-min "cooldown" period, participants' heart rates were taken with the pulse oximeter. To familiarize participants with the health walker, they were provided a demonstration of how to walk and stand on the health walker, and they were given time to practice and become comfortable with those activities.

The experimental session was composed of three phases: encoding I, encoding II, and recall.

Encoding phase I

Participants were asked to either walk or stand on the health walker. After 30 s of engaging in the designated activity, they were presented with either grid A or grid B for 45 s. After the 45 s, the grid was removed from sight and the participant entered a rehearsal phase, while continuing to engage in the assigned physical activity. They were shown a blank grid that had empty boxes labeled with numbers (from 1 to 28). The experimenter, standing next to the grid, showed one by one each object's individual picture and verbally stated its name (for all the 14 objects of the grid). Each picture was held approximately 25 cm away from the middle of the right side of the blank grid; the picture was held in that position until the participant indicated where each object was located by verbally stating the corresponding grid number. The order of the objects was pseudorandom, and the same for all participants. They were given verbal feedback as to whether their response was correct or incorrect, and the picture of the object was placed on the blank grid in the correct location (attached to the grid via Velcro); therefore, as participants recalled the objects, their pictures were progressively being added to the grid. The rehearsal was not timed; participants were instructed to take as much time as they needed. Once the last of the 14 objects was recalled and placed on the grid, the participant was given 30 additional seconds to study the grid while still engaging in the assigned physical activity. Participants were then instructed to step off of the health walker and their heart rate was measured while sitting. After this, participants entered a second 5-min "cooldown" phase in order to allow their heart rate to fall to resting. During the "cooldown" phase, participants were instructed to sit and await further instruction.

Encoding phase II

Participants followed the same procedure as for encoding phase I, except that they had to engage in the opposite activity (walk or stand) of encoding phase I, and a different grid of objects (grid A or B) was presented. Again, the order of the activity and grid presentation was counterbalanced.

Recall phase

After another 5-min "cooldown" period, participants were asked to step on to the health walker. Depending on the assigned condition, they were instructed to begin either walking or standing. After engaging in the designated activity for 30 s, the participant was shown a blank grid. The experimenter, standing next to the grid, showed one by one an individual picture of the 28 objects from both grids and verbally stated its name. Each picture was held approximately 25 cm away from the middle of the right side of the blank grid; the picture was held in that position until the participant indicated where each object was located by verbally stating the corresponding grid number. The order of the objects was pseudorandom, identical for all participants, and alternated between grid A and grid B (total of 28 objects). No feedback was provided, and the pictures were not placed on the grid. The recall phase was not timed; participants were told they could take as much time as they needed. Participants were then instructed to step off of the health walker and their heart rate was measured while sitting. Overall, the experimental session lasted approximately 45 min.

Data analysis

In Experiment 2, data from all participants were analyzed with the distance scoring method; this was the primary DV for recall because more sensitive than the hit/miss scoring. A correct response (recalling an object in the correct box) was coded as 0 points, while incorrect responses were given a score between − 1 (one box away) and − 6 (six boxes away). Each participant had an overall score for each of the two grids (learned while walking and standing) that was the sum of the distance scores for each object in that grid; this could range from 0 (perfect score) to − 84.

In addition, although a less sensitive measure of recall because this scoring method treats all errors equally (zero points), the hit/miss scoring was also used and is reported for consistency with Experiment 1.

The recall score was submitted to a 2 (within subject: grid learned while walking and standing) × 2 (between subjects: physical activity at recall) mixed-factorial ANOVA. An activity context effect would lead to a significant interaction between the grid factor and the activity at recall factor, such that there would be higher recall scores for the grid learned while doing the same activity as during recall. For example, participant walking at recall should have higher scores for the grid learned while walking compared to standing (Tables 3, 4).

Gender was not considered as a factor in the analyses because of the extremely small number of men in the sample. Male participants were spread equally among the conditions.

Results

The 2 (grid learned while walking and standing) × 2 (physical activity at recall) mixed-factorial ANOVA on distance scoring revealed a significant main effect of grid, $F(1, 30) = 5.66$, MSE = 22.88, $p = .024$, $\omega_p^2 = .03$ (see Fig. 5). Overall, participants recalled more object locations from the grid learned while standing ($M = -10.59$, SD = 6.77) compared to the grid learned while walking ($M = -13.44$, SD = 8.88). Furthermore, the main effect of the activity at recall approached significance, but was not found to be statistically significant, $F(1, 30) = 3.16$, MSE = 95.59, $p = .086$, $\omega_p^2 = .06$. Crucially, the interaction between grid and activity at recall was not statistically significant, $F(1, 30) = .43$, MSE = 22.88, $p = .519$, $\omega_p^2 = .00$. This did not support the hypothesis that participants would recall more object locations from the grid learned while engaged in a matching physical activity.

The same mixed-factorial ANOVA was run on the recall scores calculated with the hit/miss scoring (1 point per correct answer, and 0 for every incorrect answer, regardless of the distance). There was no significant main effect of grid, $F(1, 30) = 3.05$, MSE = 4.61, $p = .091$, $\omega_p^2 = .01$, or of the activity at recall, $F(1, 30) = .62$, MSE = 17.15, $p = .439$, $\omega_p^2 = .00$. Furthermore, the interaction between grid and recall activity was not found to be statistically significant, $F(1, 30) = .12$, MSE = 4.61, $p = .729$, $\omega_p^2 = .00$.

A one-way repeated-measures ANOVA was conducted on the heart rates of participants at 3 points in time: at rest after signing the consent form, after the first time they stood on the health walker, and after the first time they walked on the health walker. There was a significant difference in the heart rates across the three different levels, $F(2, 56) = 22.62$, MSE = 82.56, $p < .001$, $\omega^2 = .18$. Pairwise comparisons with

Table 3 Summary table for Experiment 2 distance scoring

Grid	Activity at recall	*M*	SD	*N*
Walk	Stand	− 10.88	6.81	16
	Walk	− 16.00	10.13	16
Stand	Stand	− 8.81	4.67	16
	Walk	− 12.38	8.14	16

Means and standard deviations for the recall score, calculated using the distance scoring method, in each of the conditions. The score for each grid ranged from − 84 to 0 (perfect score)

Table 4 Summary table for Experiment 2 hit/miss scoring

Grid	Activity at recall	*M*	SD	*N*
Walk	Stand	7.06	3.30	16
	Walk	6.06	3.47	16
Stand	Stand	7.81	2.54	16
	Walk	7.19	3.76	16

Means and standard deviations for the recall score, calculated using the hit/miss scoring method, in each of the conditions. The score for each grid ranged from 0 to 14 (perfect score)

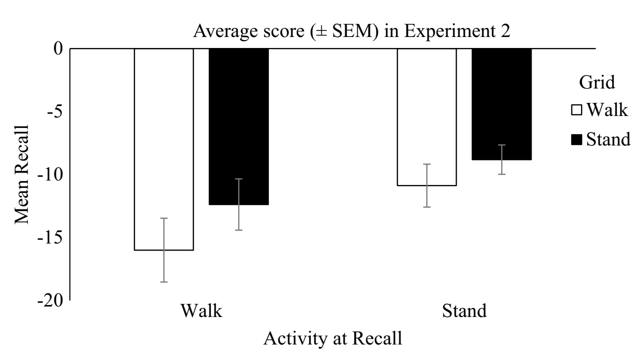

Fig. 5 Average recall score (± SEM) for recall activity and grid (learned while walking and standing) in Experiment 2 (distance scoring). There was a significant main effect of grid

Sidak correction show that the heart rates of participants at rest ($M = 83.31$, SD = 15.78) were significantly lower compared to the heart rates of participants after standing ($M = 90.76$, SD = 15.34) ($p = .016$) and walking ($M = 99.34$, SD = 18.82) ($p < .001$). Furthermore, the heart rates after standing were significantly lower than the heart rates after walking ($p = .001$).

Discussion

We hypothesized that participants would have significantly higher rates of recall for the grid that was encoded and recalled while doing the same activity; however, there was no significant interaction between the grid encoded and the activity at recall. This was evident when responses were analyzed both using distance scoring and hit/miss scoring. Therefore, the results are consistent with Experiment 1 and do not support our hypothesis. This is in contrast to Miles and Hardman's study (1998), in which participants had to learn and recall lists of words while either performing aerobic exercises via a stationary bicycle or at rest, and which showed a significant interaction between the activity at encoding and the activity at recall. The possible causes of this discrepancy are addressed in the general discussion.

When analyzing recall with the distance scoring, participants recalled significantly more object locations from the grid learned while standing compared to the grid learned while walking. These findings suggest an interference effect of the motor task on memory at encoding and are similar to the results of Experiment 1, which found an interference effect at recall. Walking may be considered more demanding than standing, and this might have competed for cognitive resources with the memory task (Darling and Helton 2014). This effect will also be addressed in the general discussion.

Finally, regarding the heart rates of participants, there was a significant difference among the measure at rest, after walking, and after standing. Heart rates were lowest at rest and highest after walking, with heart rates after standing in between the two. In Experiment 1, the heart rates did not vary significantly between standing and walking because there were no extended pauses to bring back the heart frequency to rest. (This could have confounded the measures when walking was followed by standing.) In Experiment 2, participants had to engage in a 5-min cool down upon arrival before taking their heart rate and a 5-min cool down in between encoding phases. The significant differences in heart rates suggest that the physiological state of the participants varied between the activity contexts. This is aligned with Miles and Hardman's study (1998), and therefore, it cannot be proposed that the failure to replicate their study is due to insufficient physiological changes in the state of the participants.

General discussion

Both Experiments 1 and 2 failed to find activity context effects on object location memory. When engaged in the same physical activity at testing and learning, participants did not recall significantly more locations of objects. Context-dependent memory has been reported with many different types of cues. Specifically, there is evidence of physical activity acting as a context too (Miles and Hardman 1998). Why were these results not replicated?

The failure to find a significant activity context effect in the present study is not likely due to lower statistical power related to a small sample size. Miles and Hardman (1998) obtained a significant effect with a comparable sample size (24 participants in a 4-condition repeated-measures design). Although they have not reported their effect size, upon calculation, their study's effect size was very large ($\eta_p^2 = .39$). Using this value as the anticipated effect size, with our sample size and at a significance level of .05, the power for both Experiments 1 and 2 of the present study would be .99. Alternatively, taking a more conservative approach and adopting Cohen's (1988) conventions, using $\eta_p^2 = .14$ to stand in for a large anticipated effect size, power would be .74 for Experiment 1 and .99 for Experiment 2 (with the same sample size and significance level). These power estimates were obtained through GPower 3.1 (Erdfelder et al. 1996). In sum, our attempt to replicate Miles and Hardman (1998) did not suffer from low power.

Not all of the studies on environmental context-dependent memory have reliably found significant effects (Rutherford 2000; Smith and Vela 2001). One explanation that has been proposed is the *outshining hypothesis*. The outshining hypothesis holds that individuals encode incidental contexts when learning information; however, if better retrieval cues are accessible at the time of recall, they may fail to use the incidental contexts that were encoded as retrieval cues (Smith 2013). The outshining hypothesis has been used to explain why designs that entail a suppression of ambient environment, i.e., ignoring the available environment in favor of stronger retrieval cues, are less likely to show context effects. For example, an experimental design using recognition or emphasizing inter-item association would suppress ambient environment more than a design that uses free recall at test; thus, it would be less likely to show context-dependent memory (Smith et al. 1978; Smith and Vela 2001). The outshining hypothesis may explain also the difference between the results of the current study and that of Miles and Hardman (1998). Miles and Hardman utilized a free recall task, whereas in the current study we used an object location memory task. For this type of task, the object identity is revealed to the participant at test—verbally and as an image—and this may have acted as such a strong retrieval cue to suppress the activity context cue. If true, this would suggest that object location is tied so strongly to object identity that other retrieval cues do not have a detectable effect. Future research should replicate the present study using a free recall design, in which the participant has to recall both object location and identity. This will ascertain if the null effect here is due to the outshining hypothesis or there is something special about object location memory, which renders contexts less relevant.

Another potential explanation for the failure to find activity context effects is the interference effect of the motor task on memory. In Experiment 1, participants recalled significantly less object locations when walking compared to standing at test (hit/miss scoring). In Experiment 2, participants recalled significantly less object locations from the grid learned while walking compared to the grid learned while standing (distance scoring). Before discussing this, it should be noticed that the interference effect was inconsistently detected by the two scoring methods in the two experiments. The distance scoring was theoretically a more sensitive DV than the hit/miss scoring because it provides a graded measure of location memory error that is proportional to distance; this could be a reason why, in Experiment 2, the interference effect was detected with distance scoring but not hit/miss scoring. Unfortunately, because of an accidental problem recording data in Experiment 1, not all participants could be analyzed with the distance scoring method (only 64% of the sample). The lower statistical power associated with the smaller sample size could be a reason why the interference effect was not detected with the distance scoring in Experiment 1, but it was revealed with the hit/miss scoring (whole sample).

In general, task interference is created by a lack of sufficient attentional capacity. When two tasks are similar in nature or share cognitive resources, these tasks may compete with one another when completed simultaneously. The more demanding the tasks are, the more likely they are to interfere with one another (Darling and Helton 2014). Our findings are consistent with research completed using the dual-task interference paradigm. For example, Green and Helton (2011) asked experienced climbers to complete three tasks: a traverse climbing task, a seated memory task, and a dual traverse climbing task combined with a memory task. During the traverse climbing task, participants were only asked to traverse an indoor rock climbing wall. During the seated memory task, participants were only asked to encode and recall 20 words from one of three possible word lists while remaining seated. During the dual traverse climbing and memory task, participants were asked to traverse an indoor rock climbing wall while also encoding (auditorily) 20 words from one of three possible word lists. Upon completing the climb, participants had to write down as many words as they could recall from the list learned while climbing. Recall scores obtained while engaging in the dual traverse climbing and memory task were dramatically lower (by 50%) than those who engaged in the seated memory task. Additionally, they found that individuals' climbing efficiency (but not climbing distance) was also significantly decreased when engaging in the dual traverse and memory task compared to the single climbing task. Similar results were found also by Darling and Helton (2014), and Woodham et al. (2016) and apply to cognitive tasks even beyond memory (Gage et al. 2003; Lambourne and Tomporowski 2010; Sparrow et al. 2002; Yogev-Seligmann et al. 2010). Interestingly, it seems that when a physical and a cognitive task are carried out at the same time, the physical task is prioritized (Darling and Helton 2014; Green and Helton 2011; Shumway-Cook et al. 1997), which has been explained in relation to concerns over physical safety. More attention and effort would be given to completing the physical task in a safe manner, which involves maintaining postural stability, balance, and not falling or injuring oneself (Bourdin et al. 1998).

The interference effect may account for the conflicting results between the current study and Miles and Hardman's (1998). While the current study used a health walker, Miles and Hardman engaged participants in physical activity through the use of a stationary bike. Using the health walker may have been more physically demanding than pedaling on a stationary bike, resulting in an interference in the current study that was not detected in Miles and Hardman. This interference effect could have washed away a possible activity context effect. We were surprised to find the interference effect because the motor task chosen (walking) was simple, automatic, and routinely practiced. We also had participants practice the task before the testing session began, and the danger of losing balance was diminished because participants held on the health walker handles with their hands. Furthermore, in Experiment 2 there was a rehearsal phase to acquaint participants with the movement pattern before the encoding or recall of the stimuli. Therefore, it is remarkable that walking impaired memory compared to standing. This piece of evidence adds to the literature, suggesting that memory can be impaired even by a motor task that requires very little cognitive resources. Future studies should choose a less demanding physical activity, as pedaling on a stationary bike (like in Miles and Hardman 1998); if even in this case there is interference, it would suggest that object location memory is more vulnerable than free word recall to interference by motor task. Indeed, object location memory could be more easily affected by motor interference because, as mentioned in introduction, physical activity/effort does have an effect on the representation of space

(Cohen et al. 1978; Okabe et al. 1986); in an embodied cognition perspective, the two systems (motor and spatial memory) could share cognitive resources. This is a speculation that, to the best of our knowledge, has not been addressed yet.

In conclusion, only one study has systematically addressed the use of physical activity as a context cue for memory (Miles and Hardman 1998), and context-dependent memory effects on object location memory have not been addressed at all. The present study has the merit of being the first to investigate physical activity as a sufficient context cue for object location memory. Activity context-dependent memory was not found, but an interference effect was detected. Future studies should address whether the lack of context effect is due to the recall task used, to the interference effect, or to a more specific issue with object location memory. This will be important for understanding episodic memory as it applies to spatial contexts.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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