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Walking during the encoding of described environments enhances a heading-independent spatial representation

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ABSTRACT

Previous studies demonstrated that physical movement enhanced spatial updating in described environments. However, those movements were executed only after the encoding of the environment, minimally affecting the development of the spatial representation. Thus, we investigated whether and how participants could benefit from the execution of physical movement during the encoding of described environments, in terms of enhanced spatial updating. Using the judgement of relative directions task, we compared the effects of walking both during and after the description of the environment, and walking only after the description on spatial updating. Spatial updating was evaluated in terms of accuracy and response times in different headings. We found that the distribution of response times across Headings seemed not to be related to the physical movement executed, whereas the distribution of accuracy scores seemed to significantly change with the action executed. Indeed, when no movement occurred during the encoding of the environment, a preference for the learning heading was found, which did not emerge when walking during encoding occurred. Therefore, the results seem to suggest that physical movement during encoding supports the development of a heading-independent representation of described environments, reducing the anchoring for a preferred heading in favor of a global representation.

1. Introduction

The ability to maintain spatial relations between the self and the surrounding objects and the possibility to constantly monitor the changing relations during movement are essential to guarantee adequate daily navigation. Indeed, these abilities prevent people from getting lost, allow them to re-orient and ease the identification of the right way or reference landmarks. In spatial cognition literature, spatial updating exactly refers to the ability to keep track of the changing self-to-object relations when moving (Rieser, 1989; Wang & Spelke, 2000).

According to the model by Mou, McNamara, Valiquette, and Rump (2004), spatial updating seems to be supported by the architecture of spatial representation, which involves two different representational systems: an enduring allocentric and a transient sensorimotor system.

The enduring allocentric system maintains the enduring object-to-object relations and remains stable during movement. Indeed, the spatial information retained in memory is contained in an allocentric framework, where it is not possible to perform online information updating. This system accounts for the preference of reasoning from a specific heading direction, which usually is the learning heading — that is, the initial heading direction from which the environment is encoded.

The empirical evidence actually suggests that a specific allocentric reference frame is selected from the environmental cues to store the information accordingly. In the absence of relevant landmarks, people adopt the heading direction from which they have encoded the environment as the reference frame (hereafter, learning heading), determining the preference for the learning heading (Wilson, Wilson, Griffiths, & Fox, 2007). In spatial cognition literature, the ease of reasoning from the learning heading direction compared to other heading directions is named encoding alignment effect (Kelly, Avraamides, & Loomis, 2007).

The sensorimotor egocentric system stores self-to-object information and updates online changing egocentric relations when the observer is moving inside the environment, without a considerable effort. According to the model of Mou et al. (2004), spatial updating occurs only in immediate environments, since self-to-object relations are maintained and updated only in the sensorimotor system. When spatial updating occurs, the sensorimotor alignment effect – that is, the ease of reasoning from a heading that is aligned with the observer's actual facing direction – emerges (Kelly et al., 2007).

The sensorimotor alignment effect has been commonly associated to the occurrence of spatial updating, since its positive value indicates that

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the observer updates the spatial relations as a function of her/his actual heading direction (Kelly et al., 2007). On the other hand, it is well established that the encoding alignment effect is related with the anchoring to the learning heading, since its positive value indicates that the observer relies on the heading direction from which s/he first encoded the environment (Kelly et al., 2007; Shelton & McNamara, 1997). Even though the notion of alignment effects is widely used in spatial cognition, the assumption of their independence or dependency is still controversial. Indeed, results from a recent study (Santoro, Murgia, Sors, & Agostini, 2017) seem to indicate a relation between the two alignment effects, but they are not strong enough to disconfirm previous evidence which rather suggest the independence of the effects (Avraamides & Kelly, 2010; Kelly et al., 2007).

In the immediate environments – real environments perceptually accessible in a given moment – the updating of egocentric relations occurs online and without cognitive effort because the observer completely relies on the sensorimotor system. However, it has been demonstrated that people are able to update egocentric relations also in remote environments, namely previously-experienced real environments which are not perceptually accessible in a given moment. In this case, several studies agreed in claiming that spatial updating occurs with the aid of physical movement, while imagined movement seems to be unable to foster spatial updating (e.g., Avraamides, Galati, & Papadopoulou, 2013; Rieser, Garing, & Young, 1994). In spatial updating literature, while immediate and remote environments have been widely studied, described environments have received less attention by researchers.

The occurrence of spatial updating in described environments, namely environments linguistically described and not previously experienced, has been investigated only in a few studies (e.g., Avraamides, 2003; Avraamides, Galati, Pazzaglia, et al., 2013; Rieser et al., 1994). Only some of them suggested that people were able to update egocentric relations within narratives, and physical movement seemed to be a crucial factor (Hatzipanayioti, Galati, & Avraamides, 2014; Santoro et al., 2017). The idea that spatial updating can also occur in described environments is supported by evidence suggesting that verbal descriptions are functionally equivalent to perceptual experience concerning the cognitive spatial representation produced (Loomis, Klatzky, Avraamides, Lippa, & Golledge, 2007; Lyon & Gunzelmann, 2011). Furthermore, embodied cognition suggests that while reading a story the reader could be so engaged to totally impersonate the protagonist. Indeed several studies confirmed the ease of performing actions consistent with the protagonist's and the difficulty of performing actions in opposition to the protagonist (Zwaan, 2004; Zwaan & Radvansky, 1998). Moreover, it has been demonstrated that the reader simulates perceptual and motor elements described in the story (Brunyé, Mahoney, & Taylor, 2010). Thus, if the reader imagines to be the protagonist, then s/he will act in the sensorimotor system, determining the occurrence of spatial updating within described environments.

Among the studies that investigated spatial updating in described environments, only a few focused specifically on the effect of walking (Hatzipanayioti et al., 2014; Santoro et al., 2017), compared to other physical movements, such as rotation (e.g. Avraamides, Galati, Pazzaglia, et al., 2013). In a recent study (Santoro et al., 2017), blindfolded participants were provided with a narrative describing an environment with eight objects inside and asked to mentally imagine the environment described. Then the protagonist of the narrative was described as turning 90° to the right or to the left; according to the assigned condition, participants were asked to remain still and imagine the rotation, to physically rotate or to physically rotate and walk a few steps. The results suggest that physical movement, and in particular walking, fosters spatial updating within described environments, as demonstrated by a higher sensorimotor effect. This evidence has been explained as a consequence of the different patterns of information obtained by rotation and by walking. Moreover, it has been suggested that the multisensory pattern of vestibular, proprioceptive and efferent motor information (hereafter, idiothetic information) obtained by walking can reduce the "supremacy" of the learning heading compared to the other headings.

It is noteworthy that the movements, either imagined or physically performed, involved in the previously described studies occurred only after the encoding of the environment, since movements were executed only during the protagonist's reorientation. Thus, when participants performed the movements, they had already encoded the environment with the described objects and then the information derived from movements could minimally affect the spatial representation. Indeed, in the light of the encoding alignment effect, the heading direction – which remained the same during the description of the environment – could somehow "guide" the encoding of information and, consequently, influence the corresponding spatial representation. In such a situation, it is possible that the additional information provided by movements could only enrich an already-structured spatial representation, and not fully contribute to its construction.

Based on previous evidence in literature, we wondered whether physical movement performed simultaneously with the encoding of the environment would affect spatial updating even more. Indeed, it is possible that the idiothetic information deriving from movements could significantly contribute to the construction of the spatial representation of the environment, by unbinding the reader from the learning heading. A recent study by Hatzipanayioti, Galati, and Avraamides (2014, Experiment 3) partially answered our question. The authors examined whether extensive physical movements enhanced spatial updating during the encoding of described environments, determining the occurrence of the sensorimotor alignment effect. The authors asked participants to reproduce the protagonist's movements by walking into the room as they read the narrative, and found both an encoding and a sensorimotor alignment effect. Unfortunately, they did not totally disentangle the question, since they did not systematically manipulate the effect of walking during the encoding of the environment.

Overall, our literature review highlighted that physical movements can promote spatial updating, and in particular this has been demonstrated when movements are performed after the encoding of described environments. To the best of our knowledge, only Hatzipanayioti et al. (2014) investigated the role of physical movements during encoding, but no study compared the effects of physical movements versus no movements during encoding. To better clarify this aspect, we investigated whether allowing participants to walk simultaneously with the protagonist's movements both during environment encoding and reorientation would affect spatial updating differently, compared to participants only walking during the protagonist's reorientation. We expected a higher sensorimotor effect for the participants who also walked during the description of the environment (encoding + reorientation) compared to those participants who only walked after the description (reorientation), as a consequence of enhanced spatial updating.

Thus, the present study aimed to investigate whether and how participants could benefit from the execution of physical movement during the encoding of described environments, in terms of enhanced spatial updating.

2. Method

2.1. Participants

Sixty university students (15 M; 45 F) participated in this experiment in exchange for academic credits. Their age varied from 18 to 30 years (M = 19.8; SD = 1.6). All participants signed the informed consent before starting the experiment. The participants were naive regarding the purpose of the experiment.

2.2. Experimental design

We employed an experimental design with two independent variables: Action (between subjects) and Heading (within subjects). With regard to Action, participants were randomly assigned to one of the two conditions, namely Standing (S) and Walking (W). During the encoding of the narratives, in the Standing condition, participants were simply asked to stand facing a fixed direction; in the Walking condition, participants were asked to walk through the experimental area, according to the protagonist's movements.

Similarly to previous studies (e.g., Avraamides, Galati, Pazzaglia, et al., 2013; Santoro et al., 2017), the second independent variable was the Heading, which refers to the heading which participants had to mentally adopt during a Judgement of Relative Direction (JRD) task during the testing phase (see Section 2.5 Procedure for a detailed explanation of the procedure and the testing phase). The JRD task required to mentally adopt a heading and to indicate an object from that viewpoint ("Imagine facing X, point to Y"); thus the Heading is the alignment of an imagined heading (Imagine facing) with one of three different orientations. Therefore, the Heading variable was manipulated across three conditions, which were randomized within the task. In the Learning condition participants had to imagine to be oriented with the learning heading — that is, the initial heading direction from which the participants encoded the environment. In the Testing condition participants had to imagine to be oriented with the testing heading — that is, the heading direction that participants were required to adopt after the encoding of the environment and to maintain during the testing phase. In the Opposite-to-testing condition participants had to imagine to be oriented with the opposite-to-testing heading direction — that is, the heading diametrically opposite to the testing heading. Thus, referring to Fig. 1, in the learning condition participants had to imagine facing the bar counter, while in the testing condition they had to imagine facing the stage with the piano and in the opposite-to-testing condition they had to imagine facing the loudspeaker.

The continuous arrow represents the learning heading, while the dotted arrow represents the reoriented heading after a 90° rotation to the right (testing Heading). Participants performed the task aligned with the Stage. The grey dots represent the walking path that participants usually did in the Walking condition and the footprints represent the locations in which they usually stopped.

2.3. Material and apparatus

To provide participants with auditory information (narrative descriptions and testing trials) we employed a notebook connected with Sennheiser HD515 headphones. The same notebook, running E-Prime 2 Software, was used to generate trials and perform the task.

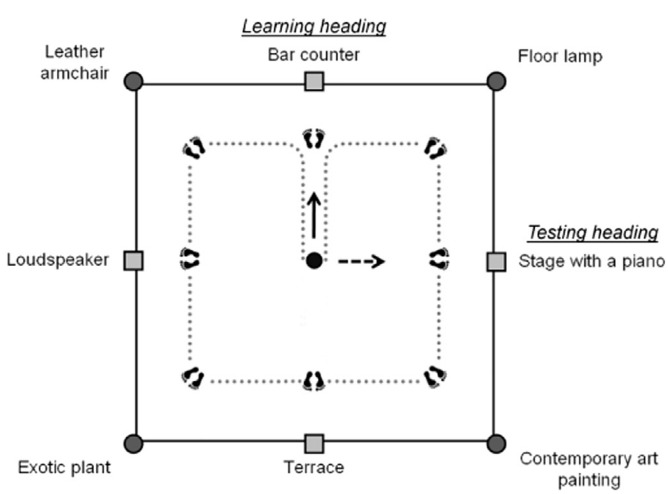

Fig. 1. Environment described in the coffee bar narrative.

2.4. Stimuli description

Two narratives were provided to participants for the experimental sessions; another narrative was used only in the practice session. The narratives were comparable in terms of number of words and a previous pilot test revealed no differences between them, in terms of both reading comprehension and encoding difficulty.[1] All the narratives were in Italian and in the second person and they described the environment in an egocentric perspective (except for a brief general introduction, which introduced the geometry of the environment). They described a protagonist walking in two different environments: a coffee bar and an office. In addition, a park was described in the practice session.

The narratives were structured similarly to those used in previous studies (e.g. Hatzipanayioti et al., 2014). In particular, the narratives consisted in ten subsequent steps. Initially, participants were provided with a brief explanation of the situation to introduce them to the story. Moreover they were provided with a description of the geometry of the environment, which was a square-shaped area with eight objects inside and the protagonist standing in the middle and facing an initial fixed direction. Then, in the following step, the first four objects were described in clockwise direction, namely, the bar counter, the lamp, the stage and the painting, referring to Fig. 1. The objects were accompanied by visual details to foster the imagination of the described environment. In the following step, explicit instructions encouraged participants to mentally visualize the environment with the objects described. Then, the remaining four objects were introduced always in clockwise direction (namely, the terrace, the plant, the loudspeaker, and the armchair). Similarly to previous objects, the objects were accompanied by visual details. Subsequently, further explicit instructions encouraged participants to mentally visualize the entire environment with all the eight objects described.

After the description of the environment, the narrative proceeded depicting the protagonist rotating 90° to the left or to the right and walking toward the object in front of her/him (that is, the protagonist's reorientation step). A following explicit instruction reminded participants to move according to the protagonist's movements and to name the object they faced after reorientation.

As in a previous study (Santoro et al., 2017), the narratives were constituted of several steps, each of which was isolated in a different auditory track; moreover, a female voice illustrated the descriptions of the environment while a male one illustrated the explicit instructions provided to the participants. These two characteristics aimed to facilitate the comprehension of the narratives.

2.5. Procedure

The experiment took place in a square-shaped area, delimited by wooden panels. Each participant was randomly assigned to one of the two Action conditions (either Standing or Walking). The experiment consisted of two experimental sessions, in which participants performed the same task with two different narratives (coffee bar and office).

The experimental sessions included a learning phase, in which the

[1] The office and the coffee bar narratives had 295 and 318 words, respectively. Fifteen participants were asked to evaluate the comprehension difficulty of both narratives by using a 7-point Likert scale (1 meant "not comprehensible" and 7 meant "totally comprehensible"). Mean scores of both office (M = 6.13; SD = 0.74) and coffee bar (M = 6.07; SD = 0.59) narratives were significantly above the central value of the scale ($t_{(14)} = 11.12$; $p < 0.001$ and $t_{(14)} = 13.48$; $p < 0.001$, respectively) and did not differ from each other ($p = 0.79$). Similarly, the participants were asked to evaluate the encoding difficulty of the environments (1 meant "very difficult" and 7 meant "very easy"). Mean scores of both office (M = 6.2; SD = 0.68) and coffee bar (M = 6.07; SD = 0.88) narratives were significantly above the central value of the scale ($t_{(14)} = 12.6$; $p < 0.001$ and $t_{(14)} = 9.06$; $p < 0.001$, respectively) and did not differ from each other ($p = 0.49$).

participants were exposed to a narrative and asked to imagine the described environment, and a testing phase, in which participants performed a Judgement of Relative Direction (JRD) task (Avraamides, Galati, Pazzaglia, et al., 2013; Hatzipanayioti et al., 2014; Santoro et al., 2017). While Hatzipanayioti et al. (2014) manipulated the visual access during the task, in the present study we decided to blindfold all the participants and to provide the narratives acoustically, since we wanted to eliminate the support of visual cues in the development of the environment representation.

Before starting the experiment, participants performed a practice session. They were exposed to the description of a park and then performed 16 JRD trials. Only when participants claimed to have correctly understood the task, the experimental procedure started. Thus, participants were blindfolded and accompanied into the experimental area, where they were positioned standing in the middle of the area, facing a wall in a fixed direction, called "learning heading" (see Fig. 1 for a graphical representation).

The learning phase started by asking participants to wear the headphones and to listen to the narrative, which included the description of the environment and the protagonist's reorientation. The requests to the participants in the learning phase differed for the two Action conditions. Indeed, during the description of the environment participants were required to imagine to be the protagonist in both conditions, but in the Standing condition, they were required to stand still, while in the Walking condition, they were required to continuously walk a few steps toward the described objects, imitating the movements of the protagonist. The participants were allowed to choose freely how many steps to take, since we did not want to influence their imagination experience somehow.[2] In both conditions, when the protagonist's reorientation occurred, the participants were asked to rotate and walk a few steps according to the protagonist's movements. After the reorientation, the participants were asked to name the object that the protagonist was actually facing, in order to monitor the adequate comprehension of the described environment. The experimenter checked the correct execution of the movements required and took note of the object's name. At the end of the narrative, the participants started the testing phase without changing their orientation; this meant that they performed the task in the same position they had after the reorientation (see Fig. 1).

The testing phase was the same for both Action conditions and was designed in accordance with previous studies (Avraamides, Galati, Pazzaglia, et al., 2013; Hatzipanayioti et al., 2014). The participants were asked to perform 16 trials of the JRD task (imagine facing X, point to Y), which consisted in pointing to a target stimulus – that is, a stimulus placed in a corner – from the imagined heading of the participant facing an orienting stimulus – that is, a stimulus placed in a canonical direction, such as in front of the protagonist. After listening to the sentence "imagine facing X", the participants were asked to press a key on the keyboard as soon as they imagined the required orientation; this response time was called "orientation latency". Then, the sentence "point to Y" started and participants were required to press one of four keys (I, M, C, R in a QWERTY keyboard) associated with each direction, in order to indicate the correct direction of Y. The direction indicated by the keys always referred to the imagined orientation of participants during each trial; thus, for instance, the key "I" always referred to the front–right corner according to the imagined orientation required during the JRD task. The four keys were marked with a protruding felt pad to ease their identification by touch, since participants were blindfolded when they performed the task. We measured both accuracy and response times, although we asked the participants to perform the task as accurately as possible, without explicitly mentioning the response times. At the end of the 16 trials, the participants were accompanied outside the experimental area and allowed to remove the blindfold and rest before the following experimental session with the second narrative started.

3. Data analysis and results

Accuracy, orientation latency and response times were considered for the data analysis. For both orientation latency and response times we ran the analyses on median scores, after eliminating outliers. To detect outliers we used the rule of > 2 SD from the mean score (2.7% of trials for the orientation latency, and 2.8% for the response times were excluded). For response times, incorrect trials (24.05%) were also excluded from the analyses. Data collected were transformed into alignment effects as suggested by Avraamides and Kelly (2010) and Avraamides, Galati, Pazzaglia, et al. (2013). In particular, both encoding and sensorimotor alignment effects were calculated for all the dependent variables, using the opposite-to-testing condition as a baseline. Basically, the rationale of this calculation is to use the opposite-to-testing heading as a baseline, since it is simultaneously misaligned with both the learning and the testing heading. Therefore, a superior performance at the learning heading compared to the opposite-to-testing heading indicates an effect of the heading from which the environment was encoded, and no influence of the body position. Conversely, a superior performance at the testing heading compared to the opposite-to-testing heading indicates an effect of the actual body position, and no influence of the initial heading direction from which the environment was encoded (for a detailed explanation, refer to Kelly et al., 2007).

In order to calculate the encoding/sensorimotor alignment effects, as regards accuracy, the mean score obtained in the opposite-to-testing condition was subtracted from the mean score obtained in the learning/testing condition. The formula was reversed to calculate the alignment effects for the orientation latency and response times: to calculate the encoding/sensorimotor alignment effects, the median score of the learning/testing condition was subtracted from the opposite-to-testing condition, respectively. Alignment (encoding vs. sensorimotor) was used as an independent variable in the statistical analyses.

3.1. Orientation latency

As regards the orientation latency, we performed a 3×2 (Heading $\times$ Action) mixed ANOVA and a 2×2 (Alignment $\times$ Action) mixed ANOVA. Both analyses did not reveal any significant effect, confirming that the time required to adopt the imagined heading does not depend on the action previously performed.

3.2. Accuracy

A 3×2 (Heading $\times$ Action) mixed ANOVA revealed a statistically significant interaction, $F(2, 114) = 5.840$; $p < 0.005$; $\eta_p^2 = 0.093$, a marginally significant main effect for Heading, $F(2, 114) = 2.786$; $p = 0.06$; $\eta_p^2 = 0.047$, and no significant main effect for Action $F(1, 57) = 2.765$; $p = 0.102$; $\eta_p^2 = 0.046$ (see Fig. 2a). Given the statistically significant interaction, we calculated two separate repeated measures ANOVAs for Standing and Walking conditions. As regards the Standing condition, we found a significant main effect, $F(2, 58) = 8.248$; $p < 0.001$; $\eta_p^2 = 0.221$. Then, we calculated the contrasts with the Bonferroni correction, showing that participants were more accurate in the Learning than in the Testing ($p < 0.005$) and Opposite-to-testing conditions ($p < 0.005$), while there was no difference between these last two conditions ($p = 0.217$). Conversely, as regards the Walking condition, no difference emerged among headings, $F(2, 56) = 1.318$; $p = 0.276$; $\eta_p^2 = 0.045$.

Analyzing the same data in terms of Alignment, we performed a 2×2 (Alignment $\times$ Action) mixed ANOVA. We found a statistically significant interaction, $F(1, 57) = 9.905$; $p < 0.005$; $\eta_p^2 = 0.148$, but

[2] It is noteworthy that all participants autonomously walked two–three steps toward the described object and then stopped for a while, until the description started again (see Fig. 1 for a depiction of the walking path).

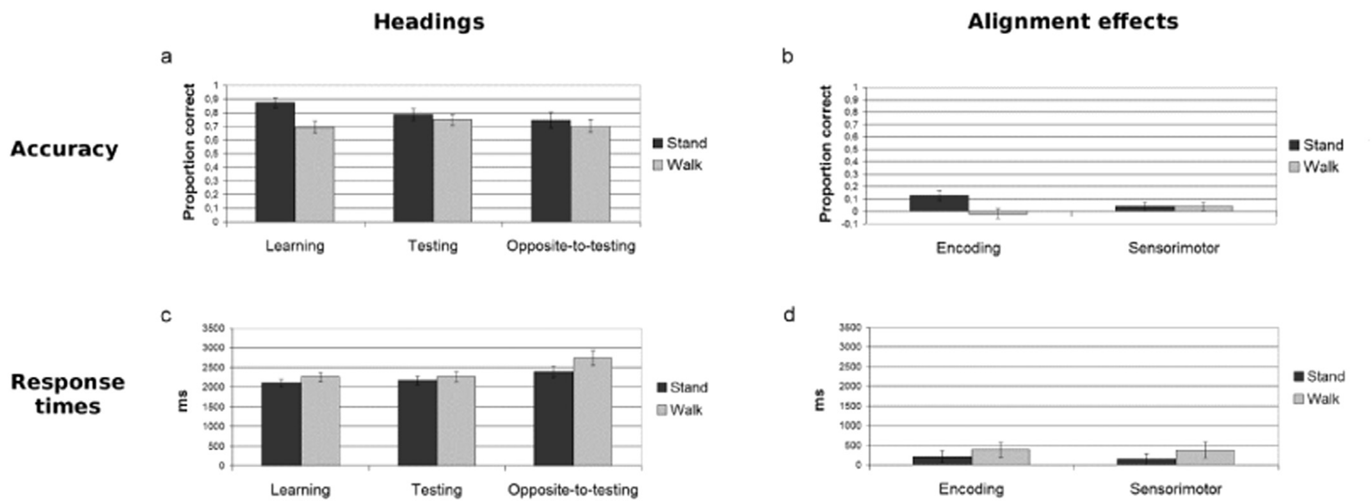

Fig. 2. Heading and alignment effects.

no significant main effect. Thus, we calculated contrasts to better investigate the direction of the interaction. The results showed a higher encoding effect in the Standing than in the Walking condition ($p = 0.01$), while no difference emerged for the sensorimotor effect between the two Action conditions (see Fig. 2b).

3.3. Response times

We performed a 3 × 2 (Heading × Action) mixed ANOVA, and found a significant main effect for Heading, $F(2, 112) = 8.799$; $p < 0.001$; $\eta_p^2 = 0.136$, but no significant values for the interaction, $F(2, 112) = 0.791$; $p = 0.456$; $\eta_p^2 = 0.014$, and for the Action main effect, $F(1, 56) = 1.652$; $p = 0.204$; $\eta_p^2 = 0.029$ (see Fig. 2c). Contrasts within Heading revealed that participants performed faster in the Learning and Testing conditions compared to the Opposite-to-testing condition ($p < 0.005$ for both of them). Conversely, no difference emerged between the Learning and Testing conditions ($p = 0.927$).

Analyzing the same data in terms of Alignment, a 2 × 2 (Alignment × Action) mixed ANOVA showed neither a significant main effect for Alignment, $F(1, 58) = 0.258$; $p = 0.614$; $\eta_p^2 = 0.004$, nor for the Action $F(1, 58) = 0.734$; $p = 0.395$; $\eta_p^2 = 0.012$, nor for the interaction $F(1, 58) = 0.156$; $p = 0.694$; $\eta_p^2 = 0.003$ (see Fig. 2d).

Heading and alignment effects for accuracy scores (a, b) and response times (c, d) in Standing and Walking conditions. Bars show standard errors. As for alignment effects, higher values correspond to greater effects.

4. Discussion

The aim of the present study was to investigate whether and how participants could benefit from the execution of physical movement during the encoding of described environments. In particular, we expected an effect of physical movement on spatial updating, hypothesizing a higher sensorimotor effect for participants who walked both during and after the description of the environment compared to those who walked only after the description. Overall, the results did not support the hypothesis of a higher sensorimotor effect in the Walking than in the Standing condition. Interestingly, we found a different distribution of accuracy scores across the Headings, depending on the physical movement.

The physical movement executed during the encoding of the environment seemed to affect the distribution of accuracy scores differently across the headings compared to the movement executed only during reorientation. Indeed, in the Standing condition participants were more accurate in the Learning condition than in the other Heading conditions, whereas in the Walking condition participants performed equally well in all Heading conditions. This evidence is further supported by the analyses on the alignment effects. These outcomes suggest that walking during the encoding of the environment negatively affects the preference of reasoning from the learning heading. However, our data rejected the hypothesis of a possible higher sensorimotor effect in the Walking condition as opposed to a higher encoding effect in the Standing condition.

Taken together, these results suggest that walking during the encoding of the environment reduces the preference for reasoning from the learning initial heading direction, favoring instead a global representation, not limited to a specific heading direction. Indeed, the reduction of the preference for the learning heading does not entail a decline of the overall performance, since the absence of the main effect for the Action condition demonstrated that the overall performance did not differ between the two Action conditions.

As regards response times, the physical movement executed during the encoding of the environment seemed not to determine an increase of the sensorimotor alignment effect compared to movement executed only during the reorientation. Actually, the data showed that participants were equally fast in reasoning from the learning and the testing heading directions, irrespective of the Action condition. In the light of the literature (e.g. Hatzipanayioti et al., 2014; Santoro et al., 2017), the fact that we did not find faster performances in the testing compared to the learning heading is quite surprising. We might speculate that it depends on some differences in the methods compared to previous studies (e.g. encoding and testing modalities, response times analyses on medians instead of on means).

Overall, the concurrent examination of both response times and accuracy scores provided us with a further point of view on our data (see Fig. 2). In particular, the distribution of response times across the Heading conditions seemed not to be related to the physical movements executed. Conversely, the distribution of accuracy scores significantly changed depending on the action executed: while in the Standing condition participants performed significantly better in the Learning condition than in the other conditions, this pattern of response did not emerge in the Walking condition, where no difference was found across the headings. According to the well-established idea that response times are related to the cognitive demands required to complete a task, based on the distribution of our results it is reasonable to hypothesize that, with a comparable cognitive effort, participants' accuracy is differently distributed across the headings depending on Action.

The main contribution of the present study to the spatial updating literature lies in the comparable levels of accuracy scores across the Heading conditions when participants walked both during the encoding of the described environments and during reorientation. Even though we expected an influence of walking on spatial updating, the core outcomes of the present study is the surprising lack of preference for the initial heading direction when walking occurred during the encoding of the environment. Indeed, this result demonstrates that physical movements performed during the encoding of described environments contribute to the construction of a global spatial representation of the environments, by unbinding participants from the learning heading.

The different distribution of accuracy scores across the headings could be due to the influence of walking on the preference for reasoning from the Learning heading. In the field of spatial cognition in narratives, a preference for the initial heading direction described, typically the learning heading, has been reported in several studies (e.g., Avraamides, Galati, Pazzaglia, et al., 2013; Franklin & Tversky, 1990). However, only the study by Hatzipanayioti, Galati, and Avraamides (2015) suggests that the participants were partially able to flexibly select the viewpoint to be adopted. In particular, it seems that the information provided by physical movements may facilitate the adoption of different headings other than the learning one (Hatzipanayioti et al., 2015). The main result emerging from the present study – that is, the homogeneous distribution of accuracy scores in the Walking condition – supports this assumption. Indeed, the continuous change of heading due to the protagonist's movements avoided participants establishing a fixed reference frame aligned with specific heading directions, allowing them to adopt different headings other than the learning one.

The flexibility of spatial representation associated with participants' movements was postulated by Simons and Wang (1998), who claimed that people are able to flexibly adjust or update their spatial representations to achieve a heading-independent representation, when enough information is available through participants' movements. This might be due to the integration of multiple viewpoints obtained from participants' walking, as suggested by Rieser (1989). The integration of multiple viewpoints has been widely investigated in the domain of spatial cognition within immediate or remote environments, whereas it has been less studied within described environments (Hatzipanayioti et al., 2015). Our results significantly extend the knowledge in the field of spatial cognition, suggesting that the integration of multiple viewpoints can occur not only within immediate or remote environments, but also within described environments; indeed walking during encoding seemed to facilitate a heading-independent representation. It is interesting to note that we did not find an actual facilitation for the other headings – that is, an increase of accuracy for the testing and/or opposite-to-testing headings – but rather a decreased performance in the learning heading.

The present outcomes contribute to a better understanding of the role of walking in spatial updating, leaving however important questions unanswered. For instance, further studies should examine why walking during encoding is not actually sufficient to promote a higher sensorimotor effect than walking only during reorientation. A possible explanation of this result could be the nature of the experimental procedure during encoding, which might not be adequate to increase spatial updating: in particular it could be too cognitively demanding for the participants or, conversely, it could provide not enough information. Further research is needed to better investigate this hypothesis as well as others. Another point which deserves to be better clarified is the role of angles of mental rotation required during testing. Indeed, while other studies in spatial cognition examined the relevance of this factor, no previous study has investigated it in the domain of spatial updating within described environments.

In conclusion, the present study provides new evidence regarding the effect of walking during the encoding of described environments on spatial representation. The main result suggests that physical movement during the encoding of described environments affects the distribution of participants' accuracy scores across the headings. In particular, it seems that physical movement during encoding reduces the anchoring for a preferred viewpoint in favor of a global representation, supporting the development of a heading-independent representation of described environments.

Appendix A. Appendix

NARRATIVE 1 (OFFICE)

You have to deliver some important documents for the rent of an apartment to the dedicated administrative office. You have easily reached the wide room in which the administrative employees work. Now, you are standing in the middle of the office, which is a square-shaped area. While you are waiting your turn, in order to spend time, you look around, turning only your head and you notice that there are eight elements in the room, which are placed in the corners and in the middle of the walls.

You walk few steps toward a large horizontally-oriented window, which is placed in front of you, through which you can see the square outside.

Then, you walk few steps toward your right and you notice that in the corner there is a luxuriant plant with many red flowers in a green ceramic vase.

You continue walking some steps toward your right and you see in the middle of the wall an old card index cabinet. It seems quite battered but it should contain a lot of documents.

Proceeding toward your right, you reach a little table with a dirty grey microwave oven.

Try to mentally visualize the environment with the objects described.

You start walking again toward your right and you notice in the middle of the wall a big closet, which is made of a grey metal and makes the room really cold.

Now, you decide to walk few steps always toward your right and you see that in the corner there is a white heater. It is really small, you think that it should be used during the winter to warm up the office.

You continue walking toward your right and you reach a writing desk. You hypothesize that it belongs to a messy employee because it is covered by a multitude of sheets.

Proceeding toward your right, you recognize a very famous design chair, which is made of red plastic.

Try to mentally visualize the environment with the eight objects described.

Then, you walk few steps to the right and go back to your initial position in the middle of the room.

At a certain point, something draws your attention. You turn 90° to your right/left and walk few steps toward the object in front of you.

Remember to move according to protagonist's movements. What is in front of you?

NARRATIVE 2 (COFFE BAR)

Today is the birthday of your friend Marco and you have decided to bring him to an event in the most popular coffee bar of the city. You have never been in this coffee bar and thus you start looking around to enjoy the environment. Now, you are standing in the middle of the coffee bar, which is a square-shaped area. While you are waiting your turn, in order to spend time, you look around, turning only your head and you notice that there are eight elements in the environment, which are placed in the corners and in the middle of the walls.

You walk few steps toward the bar counter. You can see the bar man working hard behind it.

Then, you walk few steps toward your right and you notice that in the corner there is a floor lamp, which is accurately positioned to light the center of the environment.

You continue walking some steps toward your right and you see in the middle of the wall a stage with a piano. The stage is illuminated by a suffuse lighting that makes the environment really relaxing.

Proceeding toward your right, you reach a contemporary art painting. It is made by a geometric weave with stains of vivid colours.

Try to mentally visualize the environment with the objects described.

You start walking again toward your right and you notice in the middle of the wall the door of an elegant terrace. The terrace has a lot of small sofas and elegant candles.

Now, you decide to walk few steps always toward your right and you see that in the corner there is a plant. You think that it should be an exotic species because you have never seen it before.

You continue walking toward your right and you reach a professional loudspeaker, which right now spreads a background jazz music.

Proceeding toward your right, you see a leather armchair. It seems very comfortable.

Try to mentally visualize the environment with the eight objects described.

Then, you walk few steps to the right and go back to your initial position in the middle of the room.

At a certain point, something draws your attention. You turn 90° to your right/left and walk few steps toward the object in front of you.

Remember to move according to protagonist's movements. What is in front of you?

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