The influence of encoding and testing directions on retrieval of spatial information in explored and described environments

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Ilaria Santoro[a], Fabrizio Sors[a], Serena Mingolo[a], Valter Prpic[b], Michele Grassi[a], Tiziano Agostini[a], and Mauro Murgia[a]

[a]University of Trieste; [b]De Montfort University

ABSTRACT

The verbal descriptions of an environment elicit a spatial mental model, in which the linear disposition of the described objects might be related to the properties of the description. In particular the direction from which the environment is encoded might shape the spatial mental model, as a consequence of a cultural bias in reading and writing direction. The aim of the present study was to examine the influence of the direction in which objects are encoded on the retrieval of spatial information. In two experiments we asked participants to encode an environment through either physical exploration or verbal description, that are encoding modalities which preserve the sequential presentation of spatial information. We manipulated both the encoding and testing directions of the spatial information, and tested participants by using a two-alternative forced choice task. In both experiments, the results did not reveal any significant effect, disconfirming the idea of the left-right cultural bias for western people for this type of task. The lack of effect suggests that encoding an environment through physical movement and verbal descriptions determines the development of a mental representation which is relatively independent from encoding sequential order.

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It is well–established that people are able to construct spatial mental models when reading or listening to verbal descriptions of an environment (e.g., Giudice, Bakdash, & Legge, 2007). According to the theory of mental models (Johnson-Laird, 1983) the comprehension of a text is achieved through the development of a mental model, which is a working memory representation reflecting the objects, events or situations described in the text. It seems that people share preferences guiding the construction of a mental model (Garrod & Pickering, 2004); in particular, it has been demonstrated that people tend to form a mental model in which the verbally

CONTACT Mauro Murgia mmurgia@units.it Department of Life Sciences, University of Trieste, Building W, Via Weiss 21, 34138 Trieste, Italy.

described objects are positioned in a linear array, either horizontal or vertical (for a review, see Evans, Newstead, & Byrne, 1993).

The linear disposition of objects within a mental model constructed through linguistic input, such as a verbal discourse, might be related to the properties of the input itself. Indeed, discourse has a linear nature (e.g., Levelt, 1982): the order in which objects are introduced needs to be meaningful for both the sender and the receiver. However, the direction of the linear array seems to reflect a cultural bias, based on the daily practice of a given reading and writing direction (RWD). Such a practice determines a directional habit which progressively grows and solidifies, influencing the reasoning of people (Nachshon, 1985) and the directionality of their mental representations.

According to Román, El Fathi, and Santiago (2013), the habitual RWD seems to affect cognitive activities at different levels, such as word reading (Mishkin & Forgays, 1952), lateral motion perception (Maass, Pagani, & Berta, 2007), magnitude processing (Prpic et al., 2016), and time processing (Ouellet, Santiago, Israeli, & Gabay, 2010). Moreover, habitual RWD affects also behavior activities, such as the choice of behavioral alternatives from a list (Ariel, Al-Harthy, Was, & Dunlosky, 2011) or the esthetic choice of artists (Pérez Gonzáles, 2012).

The effect of RWD on spatial representation has been studied by Jahn, Knauff, and Johnson-Laird (2007). They employed static spatial configurations, that is, a set of brief sentences describing static scenes, asking participants to evaluate the consistency of the set. The data suggested that the preference for an initial model ordered in a left–right fashion was due to the participants' habitual RWD. Thus, it is reasonable to expect that western individuals are more prone to exhibit a left–right (L–R) order organization, whereas individuals from other writing cultures, such as Arabic, are more susceptible to a right–left (R–L) order organization (Maass & Russo, 2003). A study by Román et al. (2013), in which Arabic and Spanish speaking participants were recruited, indicated that the directional lateral bias depended on the degree of exposure, and consequently practice, in specific RWDs.

The directional lateral bias might be related to the development of perceptual motor habits, such as scanning and exploration, which might also be conveyed in internal representations (Chatterjee, 2011; Maass, Suitner, Favaretto, & Cignacchi, 2009). Conversely, the interpretation postulated by Román et al. (2013) embraced an alternative view, which is an extension of the coherent working models theory (Santiago, Román, & Ouellet, 2011). According to this theory, people are prone to visually represent the language content, even though the information is provided through an auditory modality. Moreover, consistent with the strategies dealing with the maintenance of working memory, the objects are included in the spatial model in the same order in which they are described. Another central element in the explanation provided by Román et al. (2013) is the principle of internal consistency: mental models are forced to be as internally coherent and simple as possible. Thus, it seems plausible that people prefer to organize spatial information in the same order in which information was described within the text to minimize the memory load (Román et al., 2013).

The cited studies mainly employed brief sentences describing spatial relations among three objects (e.g., Román et al., 2013), which were not included within a described environment. It is plausible that the same rationale might be applicable to mental models deriving from described environments, such as room–sized spaces or parks. When people are, or imagine to be, positioned within an environment, they might be influenced by the same L–R order effect found for spatial sentences, determining a spatial information process which follows the left to right direction. When extended to a 360° surrounding environment, the L–R order direction results in a wider clockwise direction. Taylor and Tversky (1992) demonstrated that people prefer to verbally describe an environment (e.g., Convention centre) by mentioning the relevant objects in a clockwise rather than a counter clockwise direction. The authors claimed that the clockwise order is another conventional order adopted by people and posited that this preference is part of the comprehension process and is necessary to construct a unique model from the verbal description. It is noteworthy that in the study by Taylor and Tversky (1992) participants learned an environment on a map, however we do not know whether the same preference would occur when learning an environment through other modalities, such as verbal descriptions or physical exploration.

Previous studies on spatial updating (i.e., Hatzipanayioti, Galati, & Avraamides, 2014; Santoro, Murgia, Sors, & Agostini, 2017) suggested that physical walking provides a complex multisensory pattern of vestibular, proprioceptive and efferent motor information, hereafter idiothetic information (Chrastil & Warren, 2013), which is quite different from the pattern of information obtained by other sources, such as verbal descriptions. As for idiothetic information, Santoro, Murgia, Sors, Prpic, and Agostini (2017) found that, when participants walked during the encoding of described environments, their performances were not bound to the learning heading, since they performed equally well in all heading conditions, in their spatial updating study. Therefore, they demonstrated that walking during the encoding of described environments reduces the supremacy of a preferred perspective, enhancing instead a perspective-independent spatial representation. Moreover, according to the study by Hatzipanayioti, Galati, and Avraamides (2016 – Experiment 3), it is possible to expect that the direction of encoding would be less influent on spatial reasoning about environments, when the encoding of the environments is obtained through physical exploration. Indeed, it seems that the physical exploration of an environment – both real and imagined – supports the development of a global spatial representation, with no predetermined orientation.

Based on previous studies, it is not clear whether the reasoning preference according to directional lateral biases would occur also when spatial information is embedded in a meaningful spatial context. Thus, in the present study we aimed to examine whether the directional order in which elements are introduced in a physically explored (Experiment 1) or verbally described (Experiment 2) environment affects the retrieval of spatial information regarding the same elements.

Experiment 1

In Experiment 1, we studied whether the retrieval of spatial information is affected by the direction in which it is encoded, when such information is sequentially encoded through the physical exploration of the environment. According to previous evidence in literature (Hatzipanayioti et al., 2016 – experiment 3; Santoro, Murgia, Sors, Prpic, et al. 2017), we hypothesize that the idiothetic information obtained through physical walking within an environment would reduce the influence of encoding direction on the retrieval of spatial information.

Method

Participants

Thirty–six university students ($M = 15$; $F = 21$) completed this experiment in exchange for academic credits; two participants did not complete the experiment. Their age varied from 18 to 29 years ($M = 19.8$; $SD = 2.0$). All participants were native Italian speakers and reported they had no hearing limitations. Before starting the experiment, they signed the informed consent. Participants were naive as to the purpose of the experiment.

Material

A notebook running E–Prime 2 Software was used to generate trials and perform the experiment. The trials were provided through headphones Sennheiser HD515, which were connected to the same notebook. SPSS Software, G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), BayesFactor package (Morey & Rouder, 2018) and rstanarm package (Goodrich, Gabry, Ali, & Brilleman, 2018) for the R statistical software (R Core Team, 2019) were used to perform the statistical analyses.

Experimental design

We employed an experimental design with two independent variables: the direction of encoding (hereafter Encoding) and the direction of testing (hereafter Testing). Encoding and Testing were manipulated between and within subjects, respectively. With regards to Encoding, the participants were randomly assigned to one of the two conditions (Clockwise and Counter clockwise condition), and the number of participants who correctly completed the experiment was 19 and 17, respectively. The Encoding variable refers to the direction used to encode the environment, that is, the physical exploration of the environment in the clockwise or counter clockwise direction.

The Testing variable refers to the position (Left or Right) of an object from the imagined position of the participant in each trial of the testing phase. Indeed, in each trial participants were exposed to sentences such as: "you are facing the terrace, the dresser is at *your left*"; "you are facing the terrace, the bed is at *your right*". The Left condition is when the named object is located to the left of the imagined position of the participant, which implies a counter clockwise reasoning. The Right condition is when the named object is located at the right of the imagined position of the participant, which implies a clockwise reasoning.

Procedure

The experimental procedure consisted of an encoding phase and a testing phase.

Encoding phase. At the beginning of the encoding phase, participants were informed that they had to encode an environment. Then, they were blindfolded and were asked to explore the environment – a 6×4 m room containing 11 objects (see Figure 1 for a graphical representation of the room) – by walking around the perimeter accompanied by an experimenter (similar to Santoro, Murgia, Sors, & Agostini, 2019), either in a clockwise or in a counter clockwise direction. Before starting the exploration of the room, all participants were informed about the room size and their starting point (the door). Then they started walking and, as soon as they arrived at the location of an object, the experimenter re-oriented the participants towards the object; when participants were facing the object, the experimenter simply informed them they had reached the position of that specific object (e.g., "*you have reached the terrace*"). Then, the participants were re-oriented again towards the walking direction, in order to continue the

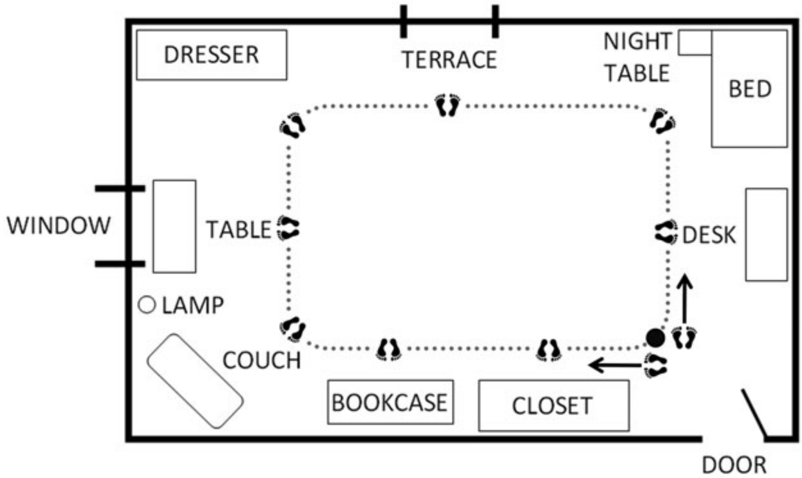

Figure 1. Graphical representation of the environment encoded in both Experiment 1 and Experiment 2. The dotted line indicates the two routes (clockwise and counter clockwise) followed by participants in the physical exploration of Experiment 1. The footprints near the starting point (black dot) indicate the orientation of participants while walking between one object and the following one; the footprints near the objects indicate the re-orientation of participants when they reached them.

exploration, until the next object was reached, and so on. The exploration ended when participants completed their route along the perimeter of the room and returned to the starting point. As it can be noticed, the verbal descriptions provided during the exploration did not contain any spatial information. They only informed participants about the objects in the room, but the spatial relations among them were acquired through physical exploration.

The participants were asked to mentally visualize the explored environment as accurately as they could. Similar to previous studies (e.g., Avraamides, Galati, Pazzaglia, Meneghetti, & Denis, 2013), the participants had the possibility to explore the environment one more time, to make sure that they had successfully visualized the room. Only those participants who declared to have sufficiently understood the explored environment were admitted to the testing phase. It is noteworthy that no participant was excluded from the experimental procedure for this reason.

Testing phase. As soon as the encoding phase ended, the participants were accompanied in a quiet room, where they were asked to sit down comfortably in front of the notebook; they were then asked to wear the headphones and to read the instructions on the monitor. In the testing phase, participants were asked to execute a two alternative forced choice task, in which they had to recognize as true or false a set of sentences regarding the location of the objects in the room.

Table 1. Prototypical example of how we created four different sentences, starting with the same first part.

First part	Second part	Direction – correctness
You are facing the terrace	The dresser is at your left.	Left – true
	The bed is at your left.	Left – false
	The bed is at your right.	Right – true
	The dresser is at your right.	Right – false

The sentences for the testing phase were in Italian and were created from a second person's point of view to foster participants' mental visualization of the room. Each sentence was composed of two parts, one regarding the position of the participant in the described room and one regarding the position of an object in the room. The first part of the sentence described the participant as facing a specific object (reference object; e.g., "you are facing the table"), whereas the second part introduced an object as positioned at the right or the left of the participant (target object).

Eight different reference positions of the participants were described in the first part of the sentence. For each of the eight reference positions we created four different versions for the second part, manipulating both the position (Left – Right) of the target objects and the correctness (True – False) of the sentences (see examples in Table 1). In all trials the target object was the one immediately at the right/left of the reference object. Thus, we created 32 sentences: 16 described the target objects at the right of the participants (eight were true and eight were false) and sixteen described the target objects at the left of the participants (eight were true and eight were false). The participants were exposed to the sentences in random order and asked to indicate whether each sentence was true or false by pressing two separate keys on the keyboard. We measured both response times and accuracy.

Data analysis

Before starting the experiment, we calculated the a priori sample size using the following parameters: effect size = .25; alpha = .05; power (1-beta) = .80. The result indicated 34 participants, and we decided to test 38 participants. With regard to accuracy, we calculated the proportion of the correct responses for each participant assigned to the Clockwise condition and for each participant assigned to the Counter clockwise condition, in both Left and Right conditions (separately). Specifically, the accuracy was calculated on the 16 trials of the Left condition, and on the 16 trials of the Right condition. Moreover, we computed the accuracy of trials which were consistent (16) and inconsistent (16) in terms of encoding and testing direction. With regard to response times, we calculated the average response times of the correctly performed trials, for each participant in each condition. In the analyses we eliminated the outliers (<2%), considering the rule of three standard deviations as a criterion. In particular, for each participant, we excluded the trials that were above three standard deviations compared to her/his individual mean. Moreover, we set a threshold of three standard deviations as cutoff to compare the mean of each participant to the mean of all participants (however, no participant was excluded from the analyses). Finally, we calculated a single performance measure combining the two dependent variables, namely response times and accuracy, by computing the ratio response times/accuracy.

Data were preliminary analyzed for normality according to the Kolmogorov-Smirnov test. Then, we applied a set of one-sample t-tests to evaluate whether the accuracy was above the chance level. Moreover, we ran a set of paired-samples *t*-tests, to compare the trials which were consistent and inconsistent in terms of encoding and testing direction. Then, we performed three 2×2 mixed ANOVAs (Encoding × Testing), to compare the performance measure, the accuracy, and the response times across the conditions.

Finally, for each comparison, we performed a set of Bayesian analyses to overcome classical inference procedure issues in supporting a null-hypothesis, computing the *null/alternative* Bayes Factor (BF_{01}). The BF_{01} is an odds ratio that contrasts the likelihood of the data fitting under the null-hypothesis with the likelihood of fitting under the alternative hypothesis (Jarosz & Wiley, 2014). Values greater than 1 indicate how many times the data are in favor of a model not including an effect (null-hypothesis) compared to a model with that effect (Jarosz & Wiley, 2014). Estimated Bayesian posterior distributions for the main effects and interactions terms were also computed (Goodrich et al., 2018).

Results

The Kolmogorov-Smirnov test revealed that the normality assumption was satisfied (performance measure: $D = .125$, bootstrap (1000) $p = .63$; accuracy: $D = .153$, bootstrap (1000) $p = .37$; response times: $D = .208$, bootstrap (1000) $p = .09$).

As for the performance measure (response times/accuracy), the 2×2 mixed ANOVA (Encoding × Testing) revealed null effects for encoding [$F(1, 34) = .001$; $p = .98$; $\eta^2_p = .001$; $BF_{01} = 2.071$], testing [$F(1, 34) = 1.611$; $p = .21$; $\eta^2_p = .045$; $BF_{01} = 2.232$], and interaction [$F(1, 34) = .928$; $p = .34$; $\eta^2_p = .027$; $BF_{01} = 2.192$]; see Figure 2, panel A. Bayesian analysis strongly supported the removal of all the main effects and interaction terms ($BF_{01} = 10.942$), in favor of a null model (see Figure 3, panel A). We found no difference in performance index between consistent and inconsistent

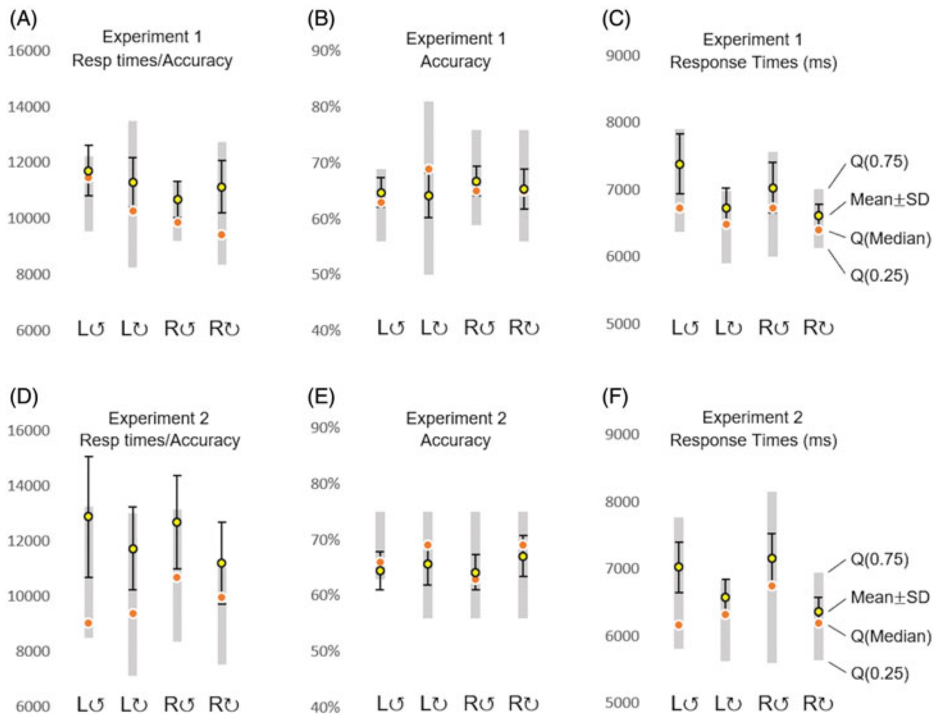

Figure 2. Performance measure (response times/accuracy), accuracy, and response times for each condition of the two experiments. L↺ = Left target – counter clockwise condition; L↻ = Left target – clockwise condition; R↺ = Right target – counter clockwise condition; R↻ = Right target – clockwise condition.

trials, in terms of encoding and testing direction [$t(35) = .078$; $p = .94$; $BF_{01} = 5.570$].

As for accuracy, we found that it was above the chance level for the Clockwise participants in both Left [$t(18) = 3.605$; $p < .005$; $d = 0.83$; $BF_{01} = .049$] and Right conditions [$t(18) = 4.119$; $p < .001$; $d = 0.94$; $BF_{01} = .018$], and for the Counter clockwise participants in both Left [$t(16) = 5.570$; $p < .001$; $d = 1.35$; $BF_{01} = .002$] and Right [$t(16) = 6.279$; $p < .001$; $d = 1.52$; $BF_{01} = .001$] conditions. The 2×2 mixed ANOVA revealed neither a significant main effect for encoding [$F(1, 34) = .133$; $p = .72$; $\eta^2{}_p = .004$; power $= .065$; $BF_{01} = 2.719$], nor for testing [$F(1, 34) = .212$; $p = .65$; $\eta^2{}_p = .006$; power $= .073$; $BF_{01} = 3.918$], nor a significant interaction [$F(1, 34) = .173$; $p = .68$; $\eta^2{}_p = .005$; power $= .069$; $BF_{01} = 9.315$]; see Figure 2, panel B. Bayesian analysis strongly supported the removal of all the main effects and interaction terms ($BF_{01} = 28.861$), in favor of a null model. Figure 3 panel B shows Bayesian posterior density curves obtained for the ANOVA coefficients. Finally, for the accuracy of trials which were consistent and inconsistent in terms of encoding and testing direction, we found that accuracy of

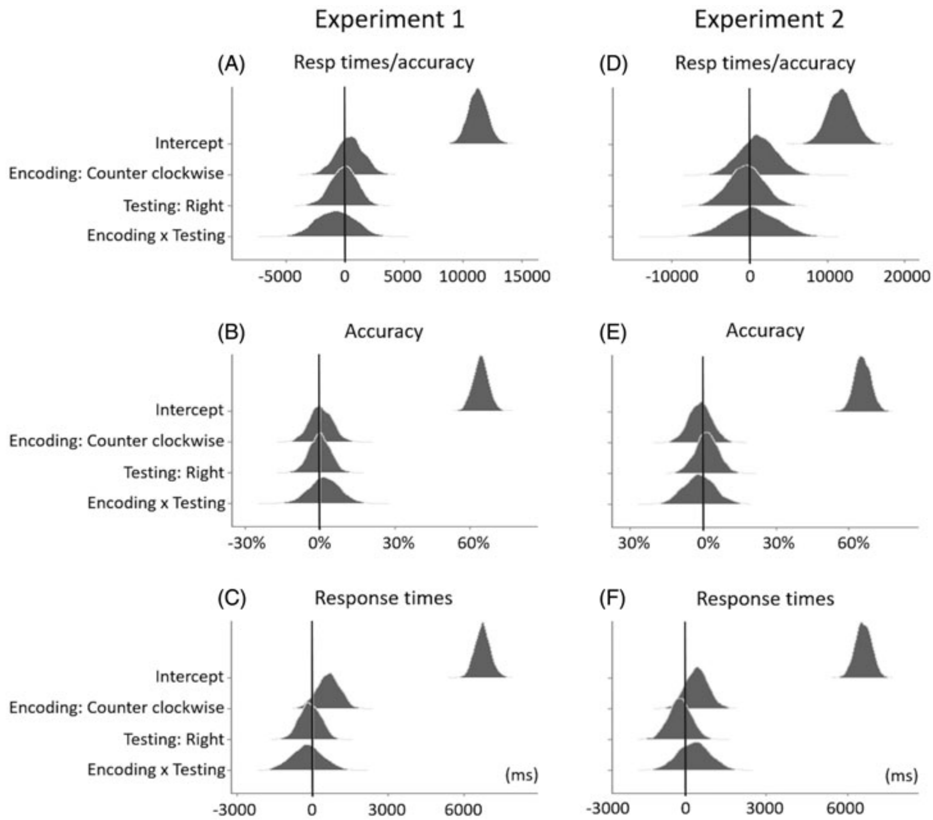

Figure 3. Estimated Bayesian posterior density curves obtained for the 2 × 2 ANOVA (Encoding × Testing) coefficients for accuracy, response times and response times/accuracy as dependent variables, in both Experiment 1 and Experiment 2.

both consistent [$t(35) = 6.299$; $p < .001$; $d = 1.05$; $BF_{01} = .001$] and inconsistent [$t(35) = 6.633$; $p < .001$; $d = 1.10$; $BF_{01} = .001$] trials was above the chance level, and that there was no difference between them [$t(35) = .363$; $p = .72$; $d = 0.06$; $BF_{01} = 5.252$].

As for response times, the 2 × 2 mixed ANOVA revealed neither a significant main for encoding [$F(1, 34) = 1.504$; $p = .23$; $\eta^2_p = .042$; power $= .222$; $BF_{01} = 1.213$], nor for testing [$F(1, 34) = 2.159$; $p = .15$; $\eta^2_p = .060$; power $= .298$; $BF_{01} = 1.591$], nor a significant interaction [$F(1, 34) = .506$; $p = .48$; $\eta^2_p = .015$; power $= .106$; $BF_{01} = 2.990$]; see Figure 2, panel C. Bayesian analysis on response times supported again the removal of all the main effects and interaction terms ($BF_{01} = 5.944$), in favor of a null model. Figure 3 panel C shows Bayesian posterior density curves obtained for the ANOVA coefficients. Finally, we computed the response times of trials which were consistent and inconsistent in terms of encoding and testing direction. We found that there was no difference between them

Table 2. Average accuracy and response times for each condition of Experiment 1.

	Clockwise		Counter clockwise	
	Accuracy (proportion)	Response times (ms)	Accuracy (proportion)	Response times (ms)
Left	.64 (± .17)	6731 (± 1261)	.65 (± .11)	7384 (± 1842)
Right	.64 (± .15)	6608 (± 787)	.67 (± .11)	7030 (± 1566)

Standard deviations are reported in parenthesis.

[$t(35) = .621$; $p = .54$; $d = 0.07$; $BF_{01} = 4.668$]. Table 2 shows average accuracy and response times for each condition.

Discussion

The present experiment aimed at investigating the influence of the direction of physical exploration of an environment on the retrieval of spatial information. According to previous evidence in literature, we hypothesized that the idiothetic information obtained through physical walking within an environment would reduce the influence of encoding direction on the retrieval of spatial information. Results seem to confirm our hypothesis.

Indeed, the analysis on both accuracy scores and response times did not reveal any significant effect, suggesting that the direction from which the environment is encoded does not affect the retrieval of spatial information about objects contained within the environment. Thus, the participants were equally accurate and fast in their performance when they explored the room in a clockwise and counter clockwise direction, and also when they had to reason about consistent and inconsistent information in terms of direction of encoding and testing. Moreover, the average accuracy confirmed that the participants successfully executed the task required, since it was above the chance level in each condition. However, the participants reported that they encountered some difficulties when reasoning about spatial relations, as demonstrated also by the relatively low value of accuracy scores (about 65%).

According to previous evidence in spatial updating literature (Hatzipanayioti et al., 2016; Santoro, Murgia, Sors, Prpic, et al. 2017), our data seem to extend the effect of idiothetic information also in the domain of spatial information retrieval. Indeed, it is possible that the idiothetic information obtained by walking supports the development of a global mental representation of the environment, which in turn eliminates, or at least reduces, the influence of encoding direction.

Experiment 2

In Experiment 2, we studied whether results similar to Experiment 1 – namely, that the information retrieval is not affected by the direction in which information is encoded – can be obtained also with a different encoding modality, which preserves the sequential presentation of spatial information. In particular, compared to Experiment 1, we decided to keep the experimental design unvaried, changing only the encoding modality, that is, using the verbal description of the environment instead of its physical exploration.

Previous evidence in spatial literature suggests that an environment verbally described is spatially, and not textually, encoded and fosters the development of a mental representation with the spatial characteristics described (Noordzij, Zuidhoek, & Postma, 2006). Moreover, it has been suggested that order effects are more bound to verbal than to spatial materials in working memory (Gmeindl, Walsh, & Courtney, 2011), and that spatial information is strategically chunked in spatial local configuration (Bor, Duncan, Wiseman, & Owen, 2003). As a consequence, it could be possible that spatial descriptions are encoded as spatial material, resulting to be relatively independent from order effects (L–R representation order of the objects) and more prone to other strategies of organization.

Thus, in the present experiment, we decided to provide participants with a verbal description of an environment, in which the objects were introduced following a clockwise or counter clockwise direction. Given the particular nature of the material to be encoded and the reduction of the order effect for spatial material (Bor et al., 2003; Gmeindl et al., 2011), it is possible to expect two main scenarios. On the one hand, the spatial description could be encoded as verbal material and would be affected by the direction lateral bias; in this case, we would find a reasoning facilitation when information is encoded according to the clockwise direction. On the other hand, the spatial description could be encoded as spatial material and would be relatively independent from the direction lateral bias; in this case, we would not find differences when information is encoded according to the clockwise or counter clockwise direction.

Method

Participants

Forty-nine university students ($M = 20$; $F = 29$) completed this experiment in exchange for academic credits; one participant did not conclude the experiment. Their age varied from 19 to 26 years ($M = 22.3$; $SD = 2.5$). Twenty-five participants were assigned to the Clockwise condition, whereas 24 were assigned to the Counter clockwise condition. All participants were native Italian speakers and reported they had no hearing limitations. Before starting the experiment, they signed the informed consent. Participants were naive as to the purpose of the experiment.

Material and experimental design

The material and experimental design were the same as in Experiment 1.

Procedure

As for Experiment 1, the experimental procedure consisted of an encoding phase and a testing phase.

Encoding phase. At the beginning of the encoding phase, participants were informed that they had to encode an environment. The encoding phase substantially differed from that employed in Experiment 1, as participants listened to the verbal description of the same environment (instead of physically exploring it). The participants were accompanied into a quiet room and asked to sit down comfortably in front of the notebook; then, they were asked to wear the headphones and to read the instructions on the monitor.

Based on the Encoding variable, there were two recorded versions of the verbal description of the environment, introducing the same eleven objects in the room either in a clockwise or in a counter clockwise direction. The two versions were tested in a pilot study to control for comprehension difficulties, and no differences emerged between them. Both versions started with an introductory description regarding the room size and the starting point of the participant (similar to Experiment 1). Subsequently, the verbal description "guided" participants through the room, informing them about the objects they would sequentially encounter along the perimeter of the room, if they walked around it in a clockwise or counter clockwise direction. The verbal descriptions were divided into four parts, one for each side of the room. As an example, this is the first part of the description of the room in the counter clockwise direction: "*You are standing at the entrance. Walking along the wall at your right, you find a desk positioned in the middle of it. Then, keeping on walking, in the corner you find a bed with a night table*".

In the encoding phase the participants were required to listen carefully to either the clockwise or the counter clockwise verbal description and to mentally visualize the described room. Participants listened to each of the four parts of the description only once. After listening to the first part, when they were ready, they pressed a key on the keyboard to listen to the second part, and so on. Similar to previous studies (e.g., Avraamides et al., 2013), the participants had the possibility to listen to the description one more time, to make sure that they had successfully understood the description and, consequently, could visualize the room. Only those participants who declared to have sufficiently understood the described environment were admitted to the testing phase. It is noteworthy that no participant was excluded from the experimental procedure for this reason.

Testing phase. In the testing phase, participants were asked to execute the same task as in Experiment 1.

Data analysis

We decided to increase the statistical power compared to Experiment 1. Therefore, before starting the experiment, we calculated the a priori sample size using the following parameters: effect size = .25; alpha = .05; power (1-beta) = .90. The result indicated 46 participants, and we decided to test 50 participants. The rest of data analyses were the same as in Experiment 1.

Results

The Kolmogorov-Smirnov test revealed that the normality assumption was satisfied for the two measured variables (accuracy: $D = .143$, bootstrap (1000) $p = .27$; response times: $D = .163$, bootstrap (1000) $p = .15$). As for their ratio (the performance measure), although we did not find satisfactory results in this test, we decided to run the ANOVA, considering the distributions overlapping among conditions[1].

As for the performance measure (response times/accuracy), the 2×2 mixed ANOVA (Encoding × Testing) revealed the null effects for encoding [$F(1, 47) = .338$; $p = .56$; $\eta^2_p = .007$; $BF_{01} = 1.651$], testing [$F(1, 47) = .151$; $p = .70$; $\eta^2_p = .003$; $BF_{01} = 4.418$], and interaction [$F(1, 47) = .030$; $p = .86$; $\eta^2_p = .001$; $BF_{01} = 3.334$]; see Figure 2, panel D. Bayesian analysis strongly supported the removal of all the main effects and interaction terms ($BF_{01} = 25.978$), in favor of a null model (see Figure 3, panel D). No difference in performance was found between consistent and inconsistent trials, in terms of encoding and testing direction [$t(48) = .026$; $p = .98$; $BF_{01} = 6.437$].

As for accuracy, we found that it was above the chance level for the Clockwise participants in both Left [$t(24) = 4.254$; $p < .001$; $d = 0.85$; $BF_{01} = .009$] and Right conditions [$t(24) = 4.588$; $p < .001$; $d = 0.92$; $BF_{01} = .004$], and for the Counter clockwise participants in both Left [$t(23) = 4.283$; $p < .001$; $d = 0.87$; $BF_{01} = .009$] and Right [$t(23) = 4.458$; $p < .001$; $d = 0.91$; $BF_{01} = .006$] conditions. The 2×2 mixed ANOVA revealed neither a significant main effect for encoding [$F(1, 47) = .187$; $p = .67$; $\eta^2_p = .004$; power = .071; $BF_{01} = 1.543$], nor for testing [$F(1, 47) = .098$; $p = .76$; $\eta^2_p = .002$; power = .061; $BF_{01} = 4.575$], nor a significant interaction [$F(1, 47) = .238$; $p = .63$; $\eta^2_p = .005$; power = .077; $BF_{01} = 3.203$]; see Figure 2, panel E. Bayesian analysis on accuracy strongly supported the removal of all the main effects and interaction terms ($BF_{01} = 22.492$), in

Table 3. Average accuracy and response times for each condition of Experiment 2.

	Clockwise		Counter clockwise	
	Accuracy (proportion)	Response times (ms)	Accuracy (proportion)	Response times (ms)
Left	.66 (± .18)	6578 (± 1347)	.65 (± .17)	7026 (± 1843)
Right	.67 (± .19)	6360 (± 1077)	.64 (± .16)	7156 (± 1838)

Standard deviations are reported in parenthesis.

favor of a null model (Figure 3, panel E). Finally, we found that accuracy of both consistent [$t(48) = 6.260$; $p < .001$; $d = .89$; $BF_{01} = .001$] and inconsistent [$t(48) = 6.142$; $p < .001$; $d = .88$; $BF_{01} = .001$] trials was above the chance level, and that there was no difference between them [$t(48) = .476$; $p = .64$; $d = 0.07$; $BF_{01} = 5.784$].

As for response times, the 2 × 2 mixed ANOVA revealed neither a significant main effect for encoding [$F(1, 47) = 2.161$; $p = .15$; $\eta^2_p = .044$; power = .302; $BF_{01} = 1.286$], nor for testing [$F(1, 47) = .105$; $p = .75$; $\eta^2_p = .002$; power = .062; $BF_{01} = 4.177$], nor a significant interaction [$F(1, 47) = 1.624$; $p = .21$; $\eta^2_p = .033$; power = .239; $BF_{01} = 1.739$]; see Figure 2, panel F. Bayesian analysis on response times supported a null model without main effects and interaction terms ($BF_{01} = 9.206$; see Figure 3, panel F). Finally, we found that there was no difference between consistent and inconsistent trials in terms of encoding and testing direction [$t(48) = 1.294$; $p = .20$; $d = 0.02$; $BF_{01} = 2.945$]. Table 3 shows average accuracy and response times for each condition.

Figures 2 and 3 allow an immediate comparison between the results obtained in Experiment 1 and Experiment 2.

Discussion

The present experiment aimed to examine the influence of the direction in which objects were encoded within a spatial description on their subsequent retrieval. Based on previous research, we hypothesized two different patterns of results. On the one hand, we could expect a positive influence of the clockwise encoding direction, due to the encoding of the spatial description as verbal information. On the other hand, we could expect the lack of influence of encoding direction, as a consequence of the elaboration of the description as spatial information. The results seem to indicate the occurrence of the second scenario, since we failed to find any significant effect for both accuracy scores and response times due to the influence of the encoding direction.

Although the average accuracy scores were relatively low (about 65%, similar to Experiment 1), it is noteworthy that statistics confirmed that the participants correctly performed the task, since their accuracy values were

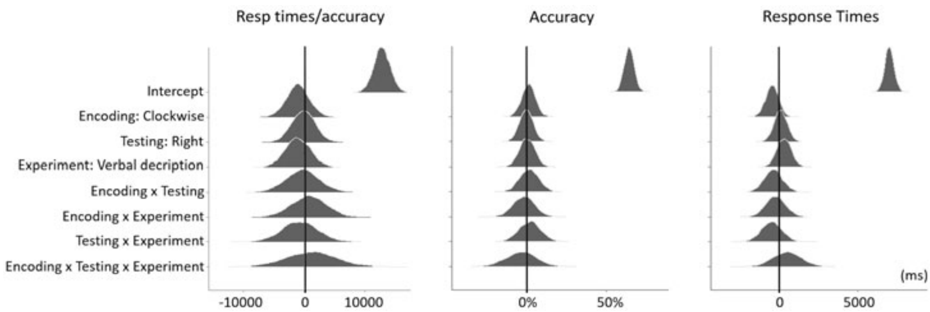

Figure 4. Estimated Bayesian posterior density curves obtained for the $2 \times 2 \times 2$ ANOVA (Encoding × Testing × Experiment) coefficients for accuracy, response times and response times/ accuracy as dependent variables.

above the chance level in each condition. Thus, even though the participants stated that the task was difficult, they were able to successfully execute it.

Different to previous studies using brief spatial sentences, it seems that spatial reasoning about the verbal description of an environment is not affected by the direction in which information is encoded. Indeed, according to our outcomes, no directional lateral bias occurred when the relevant information was embedded in a meaningful spatial context, suggesting that the verbal description of an environment is encoded as spatial material. Therefore, it is possible that the meaningful spatial context is a factor which eliminates (or at least reduces) the directional lateral bias, contrasting the influence of the encoding direction.

Cross-comparison analysis

We combined the data obtained in Experiment 1 and Experiment 2 by performing a mixed $2 \times 2 \times 2$ ANOVA (Encoding × Testing × Experiment) on performance measure (response times/accuracy), accuracy, and response times, again finding non-significant main effects and interactions; see details in APPENDIX A. Figure 4 shows Bayesian posterior density curves obtained for the ANOVA coefficients, for all three dependent variables considered.

General discussion

In the present study we examined the influence of encoding direction on the retrieval of spatial information, by employing two different encoding modalities. In Experiment 1 the participants were asked to physically explore an environment, obtaining therefore idiothetic information; according to spatial updating literature, we expected the elimination, or at least a reduction, of the influence of encoding direction on spatial retrieval. Conversely, in Experiment 2 we asked participants to encode the same environment through a verbal description; we hypothesized either the occurrence of the direction lateral bias or the lack of effects, depending on the elaboration of the spatial description as verbal or spatial material. In both experiments, we consistently found no influence of encoding direction on spatial retrieval, and no significant interaction between encoding and testing direction; this was also the case when we compared the two experiments, thus considering the encoding modality (physical exploration vs. verbal description) as a factor.

In Experiment 1, the analyses on performance measures, accuracy scores and response times did not reveal any significant effect, suggesting that the direction of physical exploration does not influence the retrieval of spatial information. Therefore, it is possible that the multisensory pattern of information obtained through the physical exploration of the environment would favor (or, at least, would contribute to) the development of a global representation of the spatial information. Consequently, by means of the global spatial representation, which has no preferred orientation, the participants could reason about spatial relations independently from the encoding direction. Therefore, consistent with previous studies (Hatzipanayioti et al., 2016; Santoro, Murgia, Sors, Prpic, et al., 2017), it is plausible that the physical movement concurrent with the encoding of an environment would make the objects' presentation order less important for the encoding and retrieval of spatial information.

In Experiment 2, the analyses on performance measures, accuracy scores and response times did not reveal any significant effect, suggesting that the spatial description was encoded as spatial material. It is possible that the spatial information embedded in a described environment is organized and maintained independently from the direction in which the information is described in the text. The meaningful spatial context in which the information is embedded seems to be an element able to determine the elimination of reasoning preference for a specific direction. According to this interpretation, our results do not support the idea of a cultural bias affecting the L–R preference as part of the comprehension process (e.g., Maass & Russo, 2003) for the verbal description of an environment.

With regard to accuracy, our data did not show any significant main effect in both Experiment 1 and Experiment 2, indicating that the Encoding and Testing directions were not able to affect participants' accuracy scores. The average accuracy was above the chance level in each condition, confirming that the participants successfully executed the task required. However, even though the average accuracy was higher than chance level, its low value suggested that participants encountered some difficulties when reasoning about spatial relations, independent of the direction of encoding or testing. Indeed, the participants reported that the task was quite hard to execute and that they needed a long time and a considerable amount of cognitive resources to solve it. Therefore, it is possible that by using a simpler task with a reduced working memory load (e.g., four items instead of eight) different results could emerge both in terms of accuracy and response times. Further research is needed to clarify this point.

In the light of previous studies revealing a preference of Western participants for reasoning in the L–R direction (Román et al., 2013), we expected a facilitation in spatial processing when the information was encoded in the clockwise direction. According to our data, neither the average performance measures, nor the response times, nor the accuracy scores revealed better values for the participants who encoded the environment in a clockwise direction than for those who encoded the environment in the opposite direction. Observing the descriptive statistics, it is possible to note a slight advantage for the clockwise condition respect to the counter clockwise condition, suggesting the occurrence of a weak direction lateral bias. Indeed, the average response times in the clockwise condition appear lower than in the counter clockwise condition (6,669 ms vs. 7,207 ms and 6,469 ms vs. 7,090 ms in Experiment 1 and Experiment 2, respectively). Although we do not totally exclude that in a certain degree a direction lateral bias might occur, the analyses revealed that the observed differences are quite far from statistical significance. Therefore, we believe that physical exploration and a meaningful spatial context have a role in the reduction of this bias.

Although the spatial information regarding object location within the environment was introduced in a linear sequential order – which was exactly the same in the Experiment 1 and Experiment 2 – it seems that the participants did not consider the sequential order when they had to organize and maintain spatial information. Therefore, it is possible that the characteristics of the encoding modalities used – namely the physical exploration and the verbal description – support the elaboration of the spatial information which is relatively independent from order effects. Therefore, our outcomes suggest that spatial reasoning in both explored and described environments is not affected by the direction in which targets are encoded, failing to confirm the results found by Taylor and Tversky (1992). It is noteworthy that their study employed a different experimental procedure, which probably is more similar to daily experience and consequently more effortless than our procedure. Thus, this difference might contribute to explain our failure to find a preference for the clockwise direction in both response times and accuracy scores.

Importantly, the cross-comparison analysis shows that encoding information from movement and language results in similar findings, and this result is in line with previous research suggesting the idea of the functional equivalence of spatial representations built from different modalities (Avraamides, Loomis, Klatzky, & Golledge, 2004; Loomis, Klatzky, Avraamides, Lippa, & Golledge, 2007; Loomis, Lippa, Golledge, & Klatzky, 2002). Thus, we can speculate that the spatial representations acquired through physical movement (Experiment 1) and through verbal descriptions (Experiment 2) are functionally equivalent. Indeed, in both cases, participants created a global representation of the environment. Given that in Experiment 1 the only source available was the multisensory information acquired through physical movement, it is evident that physical movement contributed to this representation. Notably, even in absence of movement, using a verbal description (Experiment 2), it is possible to obtain an analogous representation (thus, a functional equivalence of encoding modalities). It is noteworthy that both modalities seem to determine an environment representation independent from the L–R representational order typical of our culture. An absence of the L–R representation was recently observed in other domains (e.g., Fantoni et al., 2019), and would deserve the attention of researchers in the domain of spatial cognition.

Interestingly, although in literature several alignment effects have been described along with the effect of heading direction (e.g., Nori, Grandicelli, & Giusberti, 2006; Sulpizio, Boccia, Guariglia, & Galati, 2017), no effect of the heading direction in terms of consistence of encoding and testing direction emerged in the present study, further suggesting that participants developed a global representation of the environment which seems independent from the encoding direction. Notably, the absence of these effects was observed in both experiments, thus, independently from the encoding modality.

Future studies should examine whether a preference for the clockwise direction would emerge if different encoding and testing modalities, or different encoding and testing stimuli, are used. For example, as for the encoding modality, it could be interesting to investigate whether the same pattern of results would emerge when providing participants with a map, in which the spatial information is globally and not sequentially introduced. Moreover, it would be interesting to compare the encoding direction through the visual modality with the encoding with other modalities, but it should be done in larger environments (Wolbers & Wiener, 2014) than a room. As for encoding stimuli, the length and ease of the narratives should be manipulated, namely with shorter/longer or easier/harder narratives.

Moreover, it would be interesting to investigate the ease of encoding, by measuring the encoding time by means of paradigms allowing participants to freely encode a room, without time constraints imposed by the experimenters or by prerecorded auditory tracks (e.g., encoding object by object, at a self-selected speed). As for the task, a potential development of the present procedure would be the increase of target objects for each reference position, for example, testing four target objects instead of only two (as in the present experiment); this would allow having the distance from the reference object as variable, as well as increasing the number of trials. Finally, based on participants' claims about the task difficulty, further studies should consider the use of simplified testing sentences or even a different response modality, such as a navigation task, to control for the cognitive load engaged during the testing phase.

In conclusion, the outcomes from the present study failed to confirm the hypothesis of the cultural bias affecting the L–R preference for Western people in the retrieval of spatial information about meaningful environments, suggesting that people are not affected by the direction from which spatial information is encoded when reasoning about physically explored and verbally described environments.

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Note

1. The result of the Kolmogorov-Smirnov test was: $D = .245$, bootstrap (1000) $p < .01$. In principle, this value is not satisfactory and should imply data transformation. However, as shown in Figure 2, the performances of each experimental condition are wholly overlapped in terms of averages, standard deviations, medians and quantiles. Most importantly, all these measures show coherent profiles among conditions, thus suggesting that there were no hidden (small) effects. Based on these observations, we decided to run the ANOVA, to make results completely comparable with those of Experiment 1.

ORCID

Fabrizio Sors http://orcid.org/0000-0002-3803-1772
Serena Mingolo http://orcid.org/0000-0002-8888-6023
Valter Prpic http://orcid.org/0000-0002-1382-0951
Michele Grassi http://orcid.org/0000-0001-9512-1427

Tiziano Agostini http://orcid.org/0000-0003-0105-2999
Mauro Murgia http://orcid.org/0000-0002-8450-1157

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APPENDIX A. Detailed results of the cross-comparison analysis

As for the performance measure (response times/accuracy), the 2 × 2 × 2 mixed ANOVA (Encoding × Testing × Experiment) revealed neither a significant main effect for Encoding [$F(1, 79) = .198$; $p = .66$; $BF_{01} = 1.959$], nor for Testing [$F(1, 79) = .630$; $p = .43$; $BF_{01} = 4.450$], nor for the three-way interaction [$F(1, 79) = .002$; $p = .96$; $BF_{01} = 4.433$]. The Experiment variable did not have a main effect [$F(1, 79) = .384$; $p = .54$; $BF_{01} = 2.439$] or any interaction with the other factors [Encoding × Experiment $F(1, 79) = .156$; $p = .69$; $BF_{01} = 1.840$; Testing × Experiment F(1, 79) = .035; $p = .85$; $BF_{01} = 4.262$; Encoding × Testing × Experiment F(1, 79) = .492; $p = .485$; $BF_{01} = 2.597$]. Bayesian analysis strongly supported the removal of all the main effects and interaction terms ($BF_{01} = 1981.872$), in favor of a null model.

As for accuracy, the 2 × 2 × 2 mixed ANOVA revealed neither a significant main effect for Encoding [$F(1, 78) = .005$; $p = .95$; $BF_{01} = 2.850$], nor for Testing [$F(1, 77) = .407$; $p = .53$; $BF_{01} = 5.125$], nor for the three-way interaction [$F(1, 77) = .132$; $p = .72$; $BF_{01} = 4.241$]. The Experiment variable did not have a main effect [$F(1, 78) = .000$; $p = .99$; $BF_{01} = 3.173$] or any interaction with the other factors [Encoding × Experiment $F(1, 78) = .097$; $p = .76$; $BF_{01} = 1.764$; Testing × Experiment $F(1, 77) = .080$; $p = .78$; $BF_{01} = 3.880$; Encoding × Testing × Experiment $F(1, 77) = .408$; $p = .53$; $BF_{01} = 3.171$]. Bayesian analysis strongly supported the removal of all the main effects and interaction terms ($BF_{01} = 5010.132$), in favor of a null model.

As for response times, the 2 × 2 × 2 mixed ANOVA revealed neither a significant main for Encoding [$F(1, 79) = 3.551$; $p = .06$; $BF_{01} = 0.700$], nor for Testing [$F(1, 79) = 1.425$; $p = .24$; $BF_{01} = 2.770$], nor for the three-way interaction [$F(1, 79) = .342$; $p = .56$;

$BF_{01} = 4.015$]. The Experiment variable did not have a main effect [$F(1, 79) = .261$; $p = .61$; $BF_{01} = 2.233$] or any interaction with the other factors [Encoding × Experiment $F(1, 79) = .025$; $p = .87$; $BF_{01} = 1.952$; Testing × Experiment $F(1, 79) = .730$; $p = .40$; $BF_{01} = 3.212$; Encoding × Testing × Experiment $F(1, 79) = 2.085$; $p = .15$; $BF_{01} = 1.693$]. Bayesian analysis on response times supported again the removal of all the main effects and interaction terms ($BF_{01} = 203.013$), in favor of a null model.