Individual differences in spatial ability influence the effect of gesturing on navigation and spatial memory

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Abstract

Does producing gestures while studying routes facilitate navigation? Thirty-six participants studied route descriptions, producing congruent gestures for one route and keeping their hands still for another. When gesturing, participants made more errors and took longer to navigate the route in a virtual environment. Despite this surprising decrement in navigation performance, gesturing did not impair memory: at least for one route, gesturing actually led to better memory, particularly for navigators with lower spatial ability scores. Overall, the effects of gesturing are selective, depending on the complexity of the described route, the navigators' spatial abilities, and their previous gesturing strategies.

Index Terms: gesture, navigation, spatial memory, route learning, individual differences

1. Introduction

We frequently have to follow route directions to navigate in an unfamiliar environment. These directions may be provided by a friend guiding us over the phone, may be presented incrementally by a GPS device, or may be printed on an invitation. When having the opportunity to study route directions prior to navigation, a number of factors influence how well we represent those routes in memory. Viewing an accompanying map, for example, can help performance, especially when the spatial relations that are encoded visually in the map from a survey perspective are accompanied by linguistic descriptions from a route perspective, which encodes spatial relations relative to the navigator (e.g., "turn left" or "merge right") [1]. Other representational devices, such as arrows, have also been thought to afford schematic features useful to navigation [2] (e.g., for directional turns), and are indeed leveraged by GPS systems to supplement visual information from maps and linguistic directions.

In this study, we examine whether self-generated gestures produced when studying route directions can enhance people's representations of the to-be-navigated route in memory and, by extension, their subsequent navigation performance. Such self-generated gestures may help people construct a spatial representation of the described route by reinforcing, through their schematic features, relevant route information (e.g. directional turns). This facilitative effect could be due to sensorimotor activation from gestures that are schematically congruent with imagined turns or environmental features, resulting in improved situational representations retaining the semantic content or gist of descriptions of the environment (i.e., "situation models), in line with proposals that readers engage in experiential simulation [3].

1.1. The role of gestures in spatial tasks

A confluence of studies underscores the recruitment of gestures in spatial tasks. Speakers often gesture when they provide route directions [4], describe the location of objects in scenes [5], spatial patterns [6], or motion in space [7]. Gestures can reveal the speaker's underlying viewpoint for conceptualizing spatial information [8]. Self-generated gestures can even help in non-communicative contexts without any accompanying speech, as in tasks requiring spatial transformations, including problems that involve mental rotation [9], problems that require making spatiomotor inferences about actions [10] or about spatial relations in described environments [11]. Based on such findings, gestures have been proposed to facilitate spatial visualization and to highlight spatiomotor information for problem solving [10].

Similar to these non-communicative spatial contexts that engender gesturing, gestures in preparation for navigation may improve the spatial representation of the to-be-navigated route. In a recent study, participants who studied routes presented in diagrams recalled more steps of the route when they had gestured during an intervening rehearsal phase compared to other rehearsal conditions that included drawing the route on paper, tracing the route by hand, or mentally simulating it without hand movement [12].

Here, we address explicitly whether gestures confer a benefit to navigation *and* memory performance, not when routes are depicted through diagrams, but rather when they are presented as linguistic directions. We also investigate whether the influence of gestures on navigation and memory performance interacts with the gesturer's spatial abilities. We address these possible interactions in the next section.

1.2. Individual differences in navigation and gesturing

Two relevant lines of research are pertinent here: (i) research examining how spatial and other abilities are related to gesturing and (ii) research addressing the relationship between spatial abilities and navigation performance.

In terms of the former, there is extensive evidence that individual differences in spatial and verbal abilities are associated with differences in gesture production. For example, a combination of spatial and verbal abilities predicts gesture frequency, with the most frequent gesturers being individuals with high spatial visualization ability but low phonemic fluency (i.e., the ability to organize ideas into a chain of linguistic units, associated with executive control) [13]. Differences in fluid intelligence (the ability to select task-relevant information quickly and to focus on a limited set of task-relevant operations) also predict aspects of gesturing:

those with high fluid intelligence are more likely to produce gestures from a non-egocentric perspective in their explanations of geometric analogies compared to those with average fluid intelligence [14]. Moreover, when gestures are recruited in dual tasks, individual differences in working memory capacity influence the extent to which gestures aid performance. When having to recall a series of letters, those with low working-memory capacity benefitted from being able to gesture during an intervening explanation of how they solved a mathematical equation, whereas those with high capacity didn't benefit from gesturing [15]. Finally, differences in expertise in domains with a high spatial component (e.g., neuroscience or meteorology) are also related to differences in producing gestures, with experts being more likely to encode spatial transformations through representational gestures relative to beginners [16].

A second line of research suggests that performance in tasks that require some form of survey knowledge, including navigation, is predicted by individuals' self-reported sense of direction. For instance, sense of direction predicts participants' ability to integrate spatial information from different routes, whether routes are experienced passively while viewing a video [17] or are actively navigated in a virtual environment [18]. Also, individuals with better self-reported sense of direction can more accurately and efficiently navigate routes when they are described from a new perspective (e.g., route vs. survey) that differs from the perspective to which they had been accustomed [19]. Spatial ability may therefore be an important predictor for the effectiveness of gesturing as a learning strategy, since it may render individuals more or less likely to recruit gestures when translating linguistic descriptions into a situational representation. Indeed, beyond spatial abilities, individual preferences for navigation strategies influence the information that navigators encode and can, thus, recall (e.g., [20]).

1.3. Our study

In the present study, we examine whether the self-generated gestures that people produce when studying route directions in preparation for navigation (a) help their initial spatial representation of the to-be-navigated route, thus facilitating navigation performance, (b) help their resulting memory representation for the environment following navigation, and (c) differ in their influence on navigation and memory performance according to the gesturers' spatial abilities.

At the beginning of the study, participants completed self-report and psychometric measures intended to capture individual differences in spatial ability. Next, participants studied directions describing routes from a start point to a destination. This study phase occurred in one of two conditions: for one route participants were instructed to perform gestures congruent with the described path (Gesture), whereas for the other route they were instructed to keep their hands still (No Gesture), with their order counterbalanced across participants. Next, participants navigated those routes from memory in a virtual environment, and finally performed two memory tests that assessed their memory of the environment. This procedure was repeated for the second route.

Based on the reviewed findings that gestures can confer an advantage in spatial tasks, we expected that participants would navigate routes more accurately and efficiently and would remember the navigated environment better when gestures were permitted at study compared to when they weren't. In addition, we predicted that those with better spatial ability would generally perform better during navigation and on the memory tests for the environment. Nevertheless, our investigation of the potential interaction between spatial ability and gesturing was more exploratory. One possibility is that high spatial ability participants would benefit more from gesturing, because they are more likely to gesture spontaneously (e.g., [16]), but another possibility is that those with more limited spatial and related abilities stand to gain more from gesturing (e.g., [18]).

2. Method

2.1. Participants

Thirty-six undergraduate and graduate students from the University of Cyprus (29 female) participated for research credit for a university course or for payment (15 euros).

2.2. Materials

2.2.1. Route descriptions

Routes were described as a series of numbered steps connecting four landmark buildings. Because the two routes connected buildings in a preexisting VE (see [21], and [18]), their descriptions were not fully equivalent. As shown in Figure 1, Route 1 (the red route) was slightly more complex, involving 7 described turns (vs. 5) and 12 distinct segments of text in the directions (vs. 10) relative to Route 2. These differences permitted examining the effect of route complexity, while still matching the routes in terms of the number of landmark buildings, the number of buildings that were intervisible on the route, and the number of spatial locatives (e.g., *left*, *right*, *straight*) in their descriptions.

Figure 1: Aerial view map of the layout of buildings with two routes (solid lines) in the VE. Route 1 is shown in red and Route 2 in blue.

2.2.2. Psychometric and Self-report Measures

Participants completed the following self-report and psychometric measures: the Santa Barbara Sense of Direction test (SBSOD; [22]), the Philadelphia Spatial Ability Scale (PSAS; [23]), the Philadelphia Verbal Ability Scale (PVA; [22]), and the Spatial Orientation Test (SOT, [24]).

The SBSOD is a standardized self-report scale of 15 items designed to assess the ability to carry out tasks at the environmental scale of space (e.g., "I am very good at judging distances"). The reported analyses are based on that subset of 10 of those items (the SBSOD-CY scale), due to earlier work suggesting that that only 10 of the SBSOD items are suitable for measuring SOD in the Greek-Cypriot population [25].

The PSAS scale includes 16 items designed to measure how well participants feel they can perform small-scale spatial tasks, such as visualizing and transforming small or medium-sized objects (e.g., "I can easily visualize my room with a different furniture arrangement").

The PVAS scale consists of 10 items designed to measure how strong participants feel their verbal ability is (e.g., "I am good at crossword puzzles"). For these three self-report measures, participants responded on a 7-point Likert scale.

The SOT consists of 12 test items presenting participants with an array of objects and asking them, on a given item, to locate an object from an imagined perspective (e.g., *Imagine you are standing at the car and facing the traffic light. Point to the stop sign*). Participants draw its angle of disparity from their imagined perspective on a circle on the printed page. Participants were timed for 5 minutes to complete as many of the items as they could. Each participant's error score was computed by averaging, across items, the difference between the angle for the correct answer and their response.

2.3. Procedure

Upon giving informed consent, participants completed the self-report and psychometric measures. The SBSOD, PSAS, and PVAS were translated into Greek and were presented on a browser, using SurveyMonkey Inc. services, while the SOT was administered on paper. Next, participants were familiarized with the VE presented on a projection screen, and became accustomed to using the controls for moving and looking around the VE (a mouse and the arrow keys of a numeric keypad). Next, participants moved to an adjacent room to study a route description (study phase). They were told that they would later navigate the described path from memory in the VE, and were asked to ensure that they remembered the names of the route's four landmark buildings in order to recognize them in the VE. Participants were informed that the route description would appear on the computer screen as a series of numbered instructions that would be "similar to the format of directions from Google Maps, but more detailed". Participants could study route directions without a time limit, and were videotaped.

In the *Gesture* condition, participants were instructed to produce compatible gestures while they studied the route directions. They were asked to produce at least one compatible gesture, for each numbered step of the directions, but were otherwise free to gesture in any way the wished. In the *No Gesture* condition, participants were instructed to hold their hands still as they studied the route directions, keeping their right and left index fingers on specific keyboard keys.

After the study phase, participants returned to the original room to navigate the route from memory in the VE. They were reminded of their origin and destination buildings (e.g., "You at Batty House and you want to go to Golledge Hall."). If participants made a navigation error (e.g., taking the wrong turn) and did not readily self-correct, they were interrupted by the experimenter, directed to an earlier correct segment of the route, and prompted for the next instruction. Prompts became more specific only if the participant reported not being able to recall how to continue. If participants asked for confirmation for their navigation choices, the experimenter did not provide feedback, and asked them to proceed as they thought best.

After navigation, participants completed two tests assessing their memory representation for the virtual environment: a pointing task and a model building task. In the pointing task, for each trial, participants were placed directly next to one of the four landmark buildings of the route and were asked to point to one of the other buildings from that location. The prompt appeared at the top of the screen (e.g., "Point to Harvey House", while being next to Batty House). To respond, participants were instructed to move a crosshair that appeared in the center of the screen, until it pointed to where they imagined the front door of the building in the prompt to be. Participants could rotate the crosshair in the horizontal plane by moving their mouse and clicking to log their response. For each trial, performance was assessed by determining the smallest possible angle between the correct answer and the participant's estimate.

In the model building task, participants viewed on the computer screen a blank box with top-down views of each of the four landmark buildings of the route underneath it. Participants were told that the box represented the entire VE they had explored on that route and were asked to place each building where they considered it to be. Participants could drag and drop buildings using their mouse, adjusting their positions as much as necessary. Accuracy on the model-building task was assessed using a bidimensional regression analyses [26], which correct for differences in scale, translation, and rotation, providing the correlation coefficient between the configuration of the target map and the participant's map. The correlation coefficient squared (R^2) was the variable of interest, capturing the proportion of variance explained in the actual layout of buildings by the participant's arrangement of buildings.

Participants then completed the same procedure (study, navigation, pointing task, model building task) for a second block, in which they studied the other route in the other gesture condition (Gesture or No Gesture). After completing this series of tasks for both routes, participants were debriefed. Experimental sessions took about 1.5 hours.

2.4. Coding navigation performance

Navigation videos, captured by Fraps software, were annotated in ELAN [27] to assess the duration to transverse the route, the number of navigation errors made, and the length and frequency of their pauses. The onset of *route duration* was operationalized as the first video frame of movement at the origin of the route, and its offset as the final frame of movement (forward, backward, or lateral) at the destination building. The *navigation errors* of interest were wrong choice point errors, in which navigators deviated from the route at a decision point (e.g., a turn, intersection, crossroad, or forked road). *Pauses* were identified as the segments of the video on which the navigator was stationary, without any movement (forward, backward, or lateral) for two or more frames (i.e., sequences of video frame across which the optic flow either remained unchanged or suggested a change in heading due to rotation but not displacement). In order to control for differences in route duration, we analyzed the proportion of the route's duration that navigators spent pausing (i.e., total duration of all pauses / route duration).

2.2.1. Reliability for navigation coding

Two coders coded uniquely the videos of 15 and 17 participants, respectively, and coded redundantly the videos of another 4 participants. Their estimates of route duration exhibited high reliability in the 8 videos coded redundantly: the single measure of intraclass correlation coefficient (ICC*)* was 1.00, $p < .001$, using type consistency. The coders had a mean difference only of about a video frame (38 msecs) when identifying the end of a route. Their difference in identifying the onset of the route averaged .51 secs, due to one outlying video with a disagreement of 2.80 secs. The two coders also identified the same 18 navigation errors in the routes of the 8 videos. Their only disagreement concerned one instance in which one coder identified a navigation error that the other coder parsed as two consecutive errors. The inter-rater agreement for identifying wrong choice point errors was 95% (Cohen's Kappa = .81, $p <$ 01). The total duration of pauses per route was highly correlated between the two coders as well, ICC= 1.00, $p < .001$. The mean difference in total pause duration was 1.83 secs per route (*SD*= .43 secs), corresponding to only a small fraction of the route's total duration (.68 %).

3. Results

3.1. Navigation performance

Gesturing during the study of route directions did not improve navigation performance overall. In fact, in terms of their efficiency in navigating the route, participants took numerically longer to complete the routes when they had previously gestured (*M*=356.19 secs, *SD*= 153.72 secs) compared to when they hadn't gestured at study (*M*=326.17 secs, *SD*= 136.96 secs), F (1, 34)= 1.50, p= .23. This numerical difference in route duration can be contextualized by the number of errors participants made during navigation: participants made more navigation errors when they had gestured at study compared to when they hadn't gestured (*M*=2.03, *SD*=1.18 vs. *M*=1.58, *SD*=1.23), although this difference was only marginally significant, F (1, 34)= 3.46, p= .07. Whether navigators gestured at study did not influence their pausing behavior, F (1, 34)= .15, p= .70.

When comparing the two routes, navigators took numerically longer (by an average of 34 secs) to complete the more complex route, Route 1, F (1, 34)= 1.98, p= .17, although they paused for a significantly greater proportion of time in Route 2 (*M*= .36, *SD*= .12, vs. *M*= .29, *SD*= .13 for Route 1), F (1, 34)= 11.92, p < .01. There were no reliable differences in the navigation errors made across the two routes, F (1, 34)= .49, p= .49. For none of the above measures did the combination of the gesture condition with route identity or its order influence performance.

3.2. Navigation performance relative to individual differences

Although we didn't find a systematic effect of gesturing on navigation performance, some consistent patterns emerged when individual differences in spatial ability were considered. In general, navigation performance was better for participants with higher spatial ability scores. For instance, the mean duration of both routes taken together was significantly correlated with participants' mean SOT error (Pearson's r= .50, p < .01) and was marginally correlated with their PSAS score (Pearson's r= -.27, p= .11). Similarly, the participants' SOT error was significantly correlated with their number of navigation errors (Pearson's r= .51, p < .01) and with the proportion of the route spent pausing (Pearson's r= .37, p < .05).

Interestingly, many correlations between spatial ability and navigation performance were reliable in the No Gesture condition but not in the Gesture condition (e.g., SBSOD-CY with route duration and with navigation errors; SOT with navigation errors and with the proportion of time paused; PSAS with the proportion of time paused). That is, constricting gestures had an adverse effect on the navigation performance of individuals with lower spatial ability.

3.3. Memory performance: Pointing task

In the pointing task, gesturing at study did not influence participants' mean pointing error, F (1, 34)= 1.73, p= .20. Their mean pointing error was 42.45° (*SD*= 37.58°) when they had gestured at study and 45.04° (*SD*= 38.72°) when they had not. Although gesturing did not influence pointing performance on its own, its influence depended on the complexity of the route with which it was paired. As shown in Figure 2, gesturing improved pointing accuracy more so for the less complex route, Route 2, than for Route 1; the interaction between gesturing and the route with which it was paired was significant, F (1, 34)= 32.17, p < .001. Not surprisingly, participants were overall more accurate on the less complex route, Route 2 (*M*= 38.19°, *SD*= 36.69°) than Route 1 (*M*=49.30, *SD*= 36.39°), F (1, 34)= 32.17, p < .001.

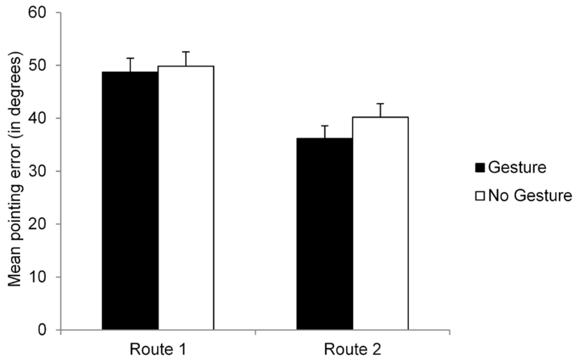

Figure 2: Participants' mean pointing error across the study condition (Gesture vs. No Gesture) and the route studied (Route 1 vs. 2). Error bars represent standard error of the mean.

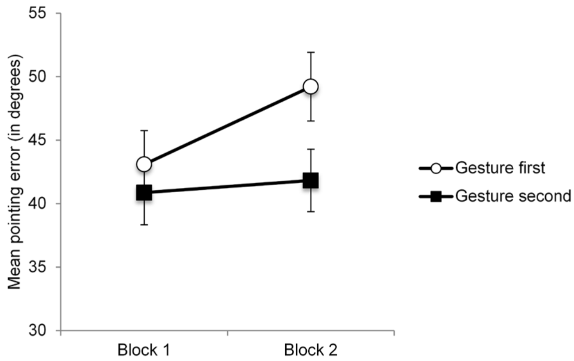

Figure 3: Participants' mean pointing error across the two blocks in the experiment (Block 1 vs. Block 2) and the order of the study conditions (Gesture-first vs. Gesture-second). Error bars represent standard error of the mean.

Finally, the ordering of the study conditions influenced pointing error to some extent, as there was a marginally significant interaction between the study condition and the block in which it took place, F (1, 32)= 3.56, p= .07. As shown in Figure 3, when the No Gesture condition was in the second block (i.e., the right circle of the "Gesture first" line) performance was worse than when it was in the first block (i.e., the left square of the "Gesture second" line), F (1, 34)= 4.05, p= .05. That is, participants who couldn't gesture after a block in which they could gesture made larger pointing errors compared to participants for whom that condition came first. This order effect was driven by Route 2, the less complex route. When participants couldn't gesture while studying Route 2, they were about 15° less accurate when this happened the second block than in the first block, F (1, 32)= 10.06, p < .01. On the other hand, when participants couldn't gesture while studying Route 1, they were comparably accurate whether this happened in the first or second block, F (1, 32)= .10, p= .76.

3.4. Memory performance: Model building

Altogether, performance in the model building task converged with performance in the pointing task. The correlation coefficients squared (R^2) indicated that gesturing at study (*M*= .72, *SD*=18) did not result in more accurate configuration than not gesturing at study (*M*= .74, *SD*= .20), F (1, 32)= .43, p= .52. However, the pairing of the study conditions with the routes mattered, as indicated by a significant interaction, F (1, 32)= 7.03, $p < .05$. As with the pointing task, when participants couldn't gesture while studying Route 2 they were less accurate, and this was specifically the case when the No Gesture condition was in the second block than the first block, F (1, 32)= 4.63, $p < .05$. As with the pointing task, participants were also more accurate on Route 2 (M= .78, SD= .18) than Route 1 (M= .67, SD= .18), F (1, 32)= 13.04, $p <. 01$.

3.5. Memory performance relative to individual differences

Participants' spatial ability predicted their memory performance in some ways. Performance in the pointing task was marginally correlated with the participants' PSAS and SBSOD-CY scores (Pearson's r= -.25, p= .15 PSAS; Pearson's r= -.27, p= .11, respectively): participants with better spatial ability tended to make smaller angular errors in the pointing task. These negative correlations became significant when only pointing performance on Route 2 was considered (for PSAS: Pearson's r = - .38, $p < .05$; for SBSOD-CY: Pearson's r= -.37, $p < .05$). Interestingly, these significant correlations held when participants couldn't gesture when studying Route 2 (N= 18, for PSAS: Pearson's r= -.66, $p < .01$, for SBSOD-CY: Pearson's r= -.48, $p < .05$), but not when they could gesture on Route 2.

In terms of model building, participants with higher spatial ability constructed more accurate configurations of the landmark buildings. Specifically, model building performance correlated significantly with PSAS scores (Pearson's r= .40, $p < .05$) and marginally with SBSOD-CY scores (Pearson's r= .33, p= .05). Similar to pointing performance, the correlation between model building performance and SBSOD-CY was significant for Route 2 (Pearson's r= .36, $p < .05$) but not for Route 1.

Participants' navigation performance was also correlated with their later performance in systematic ways. Although participants' mean angular error in the pointing task was not significantly correlated with the time they took to complete the route, this correlation became significant when only the No Gesture condition was considered (Pearson's r= .40, $p < .05$). Similarly, in the No Gesture condition, participants constructed less accurate models of the environment as route durations increased (Pearson's r= -.36, $p < .05$), whereas this wasn't the case in the Gesture condition. That is, when they hadn't gestured at study, participants made larger pointing errors and constructed less accurate models the longer they had taken to complete the route.

4. Discussion

Contrary to our predictions, gesturing while studying route descriptions did not confer a global advantage to navigation and memory performance. However, when taking the navigators' individual differences in spatial ability into consideration, a more nuanced understanding of the potential benefit of gestures emerges. For instance, although gesturing at study did not improve navigation performance (in fact, it numerically increased navigation errors), those with lower spatial abilities were worse at navigating when gesturing was prevented at study. Measures of spatial ability reliably predicted navigation performance only in the No Gesture condition, with one exception (between SOT and the mean route duration, whose significant correlation held for both study conditions). In other words, preventing gestures during the study phase was especially pernicious to those with lower spatial abilities. For these individuals, constricting gestures at study may have contributed to a less accurate initial representation of the route and the environment compared to when they had been instructed to gesture.

This proposal is supported by the memory tests, on which lower ability navigators performed worse, though in a more restricted context. When gestures were constricted, there was a decrement in pointing performance for the less complex of the two routes (Route 2), on which participants were overall more accurate. It is not fully clear why these effects of gesturing (or not gesturing) are observed only for Route 2, since performance on Route 1 does not seem to reflect a floor effect any more so than performance on Route 2. In both the pointing and model building tasks, performance on this route was worse when gestures were constricted in the second block (i.e., after having used a gesturing strategy), especially for navigators with lower spatial abilities. This order effect is in line with other studies reporting a performance cost when switching from a gesture to a no gesture condition (e.g., [15]).

When interpreting the findings of the navigation and testing phases, it is useful to distinguish the representations of the environment that participants accessed in each of these phases. During navigation, participants presumably accessed an *initial* representation of the environment; this representation had, as its input, the linguistic descriptions provided at study and, in the Gesture condition, self-generated gestures that presumably elaborated or reinforced their initial situation model. During memory testing, participants accessed their *final* representation of the environment, which had been enriched and updated by the visual information experienced during navigation in the virtual environment. This distinction qualifies some patterns that may appear perplexing otherwise: for instance, that Route 2 exhibited worse navigation performance in some ways but better memory performance. The fact that participants paused proportionally longer when navigating Route 2 (vs. Route 1) may have enabled them to create a more accurate representation of the environment along that route, resulting in more accurate pointing judgments and model reconstructions later on.

However, what remains puzzling is that, although constricting gestures impaired the navigation and memory performance of low ability navigators, gesturing led to overall more navigation errors compared to not gesturing (albeit, this was a marginally significant difference) and numerically longer route durations. One possibility for this counterintuitive finding is that *forcing* participants to gesture taxes their cognitive or attentional resources, and thus impairs their encoding of the environment. Other researchers have not found evidence in support of this claim, reporting no reliable differences between the effects of forced and spontaneous gesturing (e.g., [28] in a dual task). Still, in our task, it is possible that there could be an adverse effect of forced gesturing.

Another possibility is that, by gesturing while encoding route descriptions, readers may reinforce somewhat inaccurate inferences about an unfamiliar environment. Linguistic directions convey spatial information through discrete units that do not capture analogue or gradient spatial relationships. For example, readers may interpret the description of a "left turn" as a canonical 90° left turn, when in fact it may refer to a more oblique turn (say, 75°) in the environment. Thus, when readers are trying to construct situation models for unfamiliar environments, asking them to produce compatible gestures could reinforce more canonical representations for some aspects of the environment that may conflict somewhat with their perceptual experience during navigation, sufficiently so to result in navigation errors. This suggests that, although constricting gestures when studying route directions may be particularly harmful to low spatial ability individuals, forcing navigators to gesture on each instruction may not be an ideal encoding strategy overall. Although in this experiment we did not code for the type and frequency of gestures produced (having simply checked that participants behaved as instructed in the Gesture and No Gesture conditions), we are doing so in a follow-up experiment.

In this new experiment, we are aiming to shed light on the reported decrement in navigation performance here by letting participants gesture spontaneously instead of instructing them to gesture. If spontaneous gesturing *is* beneficial to navigation performance, the numerical decrement in navigation performance observed here could have been due to forced gestures taxing participants' cognitive resources. However, if spontaneous gesturing continues not to improve navigation performance, then it may be a non-ideal strategy for encoding routes in unfamiliar environments, as it could contribute to more schematic and slightly inaccurate spatial representations. With 2/3 of these new data coded, more than half of the gestures encode representational features of the environment or route (8.41 out of the 15.25 gestures produced on average per minute), involving a route or survey perspective, or their combination. Examining the distribution of gesture types and their frequency will be useful to unveiling the strategies that navigators employ at study and their relationship to the navigators' spatial abilities and subsequent performance.

So far, the effect of gesturing on navigation and memory performance appears to be selective, depending on the complexity of the described route, the spatial abilities of the navigators, and their previous learning strategies (e.g., the prior availability of gestures).

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