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RESEARCH NOTE

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Interaction of visual and idiothetic information in a path completion task

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Abstract To assess the contribution of visual and vestibular information on human navigation, five blindfolded subjects were passively displaced along two sides of a triangular path using a mobile robot. Subjects were required to complete the triangle by driving the robot to the starting point either blindfolded or in full vision in a 7×6-m and a 38×38-m room. Room dimensions exerted a significant effect on performances: in the smaller environment blindfolded responses were always too short whereas subjects correctly reached the starting point when visual feedback was allowed. On the contrary, in the larger room subjects correctly responded while blindfolded but drove significantly farther than requested in full vision. Our data show that vestibular navigation is highly sensitive to both stored (knowledge of environment) and current visual information.

Keywords Navigation · Triangle completion · Vestibular system · Distance estimation · Idiothetic information

Introduction

As stated by Pythagoras' theorem, in order to compute the hypotenuse of a rectangular triangle, the size of its sides must be known. We used a navigational version of this problem, providing blindfolded subjects with vestibular and somesthetic information (i.e. idiothetic information: Mittelstaedt and Glasauer 1991) about their displacements along the two sides of a rectangular triangle. During motion, idiothetic inputs should allow updating of the relations between the body and the environment in order to retrieve actual position and orientation in space. While several reports have shown that when vision is prevented, idiothetic cues can provide only a gross orientation (Mittelstaedt and Glasauer 1991; Loomis et al. 1993; Israël et al. 1993; Marlinsky 1999), other experiments have shown that after passive translation in darkness, these same cues allow subjects to correctly reproduce the previously imposed distance (Berthoz et al. 1995; Israël et al. 1997; Grasso et al. 1999). Therefore, the question of whether the brain can compute distance on the basis of idiothetic information alone still remains unanswered. Here we report the first evidence that, when vision is prevented, stored idiothetic information can be used to correctly estimate the distance required to complete a triangular path, provided there is an environment of adequate dimensions.

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Materials and methods

Five blindfolded subjects (two women, three men, mean age 30±5 years) gave their written consent and participated in the experiment, which was approved by the local ethics committee. Subjects sat on a motorised four-wheeled robot (Robuter, Robosoft SA, France; see Berthoz et al. 1995) and were passively transported along the two sides of a triangular rectangular path (Fig. 1). Subjects were told that the turning between the sides was a 90° angle and that both sides were of the same length.

During this phase of passive transportation (0.5 m/s peak velocity for the translations, 50°/s peak velocity for the rotations, both with a triangular velocity profile), the robot was controlled through a computer via wireless modems. As depicted in Fig. 1, the robot was displaced from the starting point (SP) to a location A, then after a rotation of 90° it was further displaced to B, where a rotation of 135° oriented it toward SP. After a 5-s interval, subjects were asked to return to SP by driving the robot themselves by means of a joystick. Since the joystick did not allow any deviation from a straight trajectory, subjects could use it only to control the robot's velocity. All subjects were trained on using the joystick before starting the experimental session.

During the whole task, subjects had their head restrained by cushioned supports and wore headphones delivering white noise to prevent acoustic cues. During passive transportation subjects wore

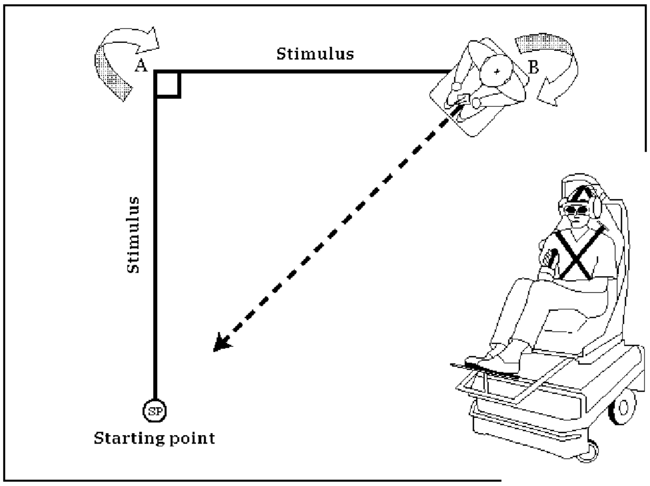

Fig. 1 Schematic view of the trajectories and the robot used in the study (see text for details)

goggles with blacked-out lenses to suppress visual information; in the condition with response in full vision goggles were opened during the 5-s pause following the second rotation of the robot (location B in Fig. 1). Before each trial blindfolded subjects were disoriented for about 30 s by randomly displacing the robot in the room.

Stimulus paths of three different dimensions were used, with sides (SP-A and A-B) of 1.5, 2 and 3 m. Two fixed sequences of 18 randomised stimuli (6 for each path, 3 with left and 3 with right turn at both points A and B) were run either with or without visual feedback during response (full vision or blindfolded response conditions). Order of conditions was counterbalanced among subjects. The experimental session was run in a 7×6-m empty room and repeated 1 month later in a 38×38-m empty hangar. In both cases there was a uniform neutral colour on the floor and subjects never started a trial in the same position relative to the room; thus no visual cue could be used as a valid landmark. Subjects were all familiar with both environments since before the experimental session they were allowed to freely move around, driving the robot in full vision in order to practice using the joystick. Moreover, condition assignment followed an ABBA design: thus, half of the subjects had an even larger visual experience of the room because they started the experimental session responding in full vision.

Optically encoded digital odometry (100 Hz) of the distance driven by the subjects during response was transferred after each trial from the robot to the computer through the modems. Gain of distance (ratio between the distance driven by the subject and the distance necessary to close the triangular path), gain of duration (ratio between duration of response and the time of passive transportation along an outbound leg of the path) and gain of peak velocity (ratio between peak velocity of the robot during response and during passive transportation along the stimulus path) were submitted to ANOVA for repeated measures with the room's size (small and large), condition (full vision or blindfolded response) and stimulus dimensions (triangle 1, 2 and 3) as factors.

Results

Mean gain (and SD) of distance, peak velocity and duration of responses in each condition are summarised in Table 1. Figure 2 shows the average distance travelled by the group of subjects in each condition. Data show that in the smaller room blindfolded subjects failed to complete the triangle, namely they always stopped driving the robot too early (see Fig. 2, left panel). Indeed correct distance estimation would lead to a gain of 1 (i.e. the ratio obtained if the subject's response matched the required distance exactly), whereas in this condition the distance gain was always smaller (see Table 1). On the contrary, when subjects gave their responses in full vision they correctly reached the starting point.

In the hangar, the pattern of results was quite different: when responding while blindfolded, subjects correctly estimated the length of the hypotenuse and succeeded in reaching the starting point, while when allowed to drive the robot with eyes open, subjects drove far beyond the required distance (see Fig. 2, right panel).

Since a preliminary ANOVA showed no difference between responses to stimuli with right or left turns, analyses were run on gain of collapsed data. ANOVA revealed main effects of room size, condition (blindfolded and full vision response) and distance (triangle size) and no significant interactions. Both gain of distance and duration were greater in the hangar (mean distance gain: 1.12±0.27; mean duration gain: 0.87±0.08) compared to the small room (mean distance gain: 0.88±0.20; mean duration gain: 0.79±0.07, $P<0.03$). No significant difference was found for gain of peak velocity (hangar: 1.14±0.22; small room 1.02±0.23).

When subjects were allowed to see during response, they drove farther and faster (mean of gain for distance: 1.14±0.25; for duration: 0.85±0.10; and for peak velocity: 1.22±0.18) than when responses were given while blindfolded (mean distance gain: 0.86±0.20, $P<0.007$; mean duration gain: 0.80±0.07, P=NS; mean peak velocity gain: 0.94±0.20, $P<0.005$).

Finally, distance gain decreased with increasing path dimensions ($F_{(2,8)}=14.897$, $P<0.003$, mean gain: 1.09±0.28, 0.996±0.25, 0.9±0.26 with stimulus 1, 2 and 3, respectively); namely errors increased with larger stimuli.

A *t*-test for each condition was run on subjects' mean gain of distance (their actual performance) in order to assess differences from the value of 1 (the ideal performance). In the small room responses were significantly shorter than requested only in the 'blindfolded' condition

Table 1 Means and SDs of gain of distance, velocity and duration of responses in each condition. Gain of distance is the ratio between actual and expected response. Gain of velocity and duration is the ratio between velocity and duration of the response and an outbound leg of the stimulus path

Response gain	Small room		Large room	
	Blindfolded	Full vision	Blindfolded	Full vision
Distance	0.75 (±0.12)	1.01 (±0.11)	0.96 (±0.18)	1.28 (±0.24)
Peak velocity	0.85 (±0.021)	1.19 (±0.014)	1.03 (±0.007)	1.26 (±0.019)
Duration	0.9 (±0.032)	0.91 (±0.034)	0.93 (±0.034)	1.05 (±0.012)

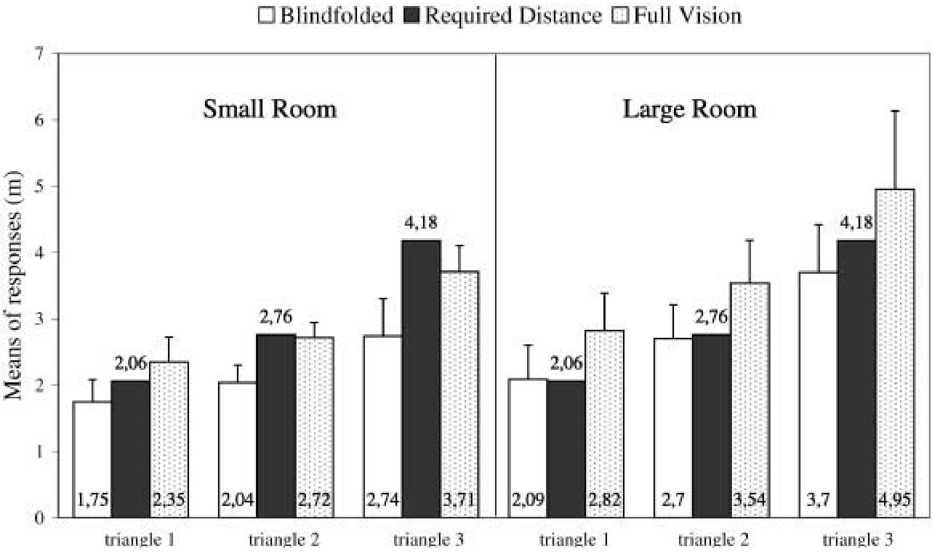

Fig. 2 Means and SD of the distance travelled during the response in the small (7×6 m) and in the large room (38×38 m). The *black bars* show the required distances according to the three stimulus dimensions; the *white bars* show mean of responses when subjects drove the robot while blindfolded; the *spotted bars* depict mean of responses given in full vision

(t=–6.558, *df*=14, *P*<0.0001; 'full vision' condition: *t*=0.144, *P*=NS); the opposite was found in the hangar: gain of responses was significantly greater than 1 only when responses were given in full vision (*t*=4.207, *df*=14, *P*<0.001; 'blindfolded' condition: *t*=–0.767, *P*=NS).

A *t*-test was also run on mean gain of duration in order to assess difference from the value of 1, namely the value expected if subjects reproduced time elapsed during passive transportation along an outbound leg of the path. Analysis showed that subjects' responses matched duration of one leg of the path only when subjects drove blindfolded in the larger room (*t*=–3.381, *df*=2, *P*=NS; 'full vision' in the hangar: *t*=7.408, *P*<0.02; 'blindfolded' condition in the small room: *t*=–5.297, *P*<0.04; 'full vision' condition in the small room: *t*=–4.801, *P*<0.05). The same analysis on gain of peak velocity during response revealed that subjects never reproduced this stimulus feature and that peak of velocity during response was always significantly different: it was greater in all but one condition, namely when responding blindfolded in the small room (*t*=–11.942, *df*=2, *P*<0.007; full vision in the small room: *t*=22.618, *P*<0.002; 'blindfolded' condition in the hangar: *t*=7.918, *P*<0.02; 'full vision' condition in the hangar: *t*=23.264, *P*<0.002).

Discussion

In the present experiment, blindfolded subjects were passively transported along the two equal sides of a triangular path by a mobile robot, then they were asked to complete the triangle by driving the robot precisely to the starting point. Since it has been suggested that in triangle completion the main source of error is angular estimation (Mittelstaedt and Glasauer 1991; Loomis et al. 1993; Marlinsky 1999), in the present case subjects were always oriented towards the starting point before each response. Thus they only had to estimate distance. We were interested in assessing whether subjects could perform a mental spatial operation akin to solving a geometry problem, namely to find the length of the hypotenuse of a rectangular triangle on the basis of stored idiothetic information. Our results show that this is possible although under specific constraints.

In our experiment when responding blindfolded subjects could rely only on temporal, vestibular and proprioceptive information. Therefore, since a copying strategy (i.e. matching the stimulus' parameters) would never allow reaching the starting point, we suggest that subjects really attempted to compute a new distance on the base of stored idiothetic information.

In blindfolded response, to make their estimate subjects were likely forced to use a 'look-behind' strategy, namely to rely on the sensory feedback derived from robot motion to decide when a sufficient distance had been travelled. In other words, subjects built their responses while driving the robot. When vision was allowed during response, we suggest that an alternative strategy could be used: subjects could visually locate the estimated endpoint of the response and then drive the robot straight there ('endpoint' strategy).

The present data show that probably both strategies are independently used according to the availability of visual feedback during response and depending on the environment in which the task is performed.

When subjects relied on idiothetic information alone, they could correctly reach the starting point, as shown by blindfolded responses in the hangar. On the contrary, the undershoot we found in the same condition in the small room may result from fear of bumping into the walls rather than from a defective ability in distance estimation. Indeed, subjects knew that most responses would bring them very close to the walls and results showed a significant reduction of peak velocity of response compared to both stimulus and responses in all the remaining conditions. An analogous effect of 'estimation's shortening' was described in 1955 by Werner and Wapner in a task in which blindfolded subjects were required to reach a previously observed target by walking either parallel (‘neutral’ condition) or towards the edge of a theatre stage (‘danger’ condition). Walked distance, speed and pace were significantly reduced in the ‘danger’ condition. The authors introduced the term of ‘psychological distance’ to underline the cognitive interference of emotional factors (danger and/or fear) on the computation of a distance. Our results seem to confirm this interpretation; indeed, when a ‘neutral’ condition was created by allowing response in full vision, subjects felt safe, drove the robot significantly faster and accurately reached the starting point also in the small room.

Since idiothetic information appears to be sufficient to correctly solve the task, does visual information have only a supporting role? In the small room availability of visual information could have provided a better estimation either by helping subjects to drive more safely in a limited space or providing spatial cues useful to minimise errors, i.e. distance from the walls and/or room’s dimensions. It should be noted that in the full vision condition, responses are always faster. However, we cannot exclude that at the end of the transportation phase, when subjects were allowed to see, they used vision to locate the starting point in the room before moving for the response (‘endpoint’ strategy). An ‘endpoint’ strategy is likely used in the greater environment, where subjects drove the robot far beyond the required distance and faster than in the passive transportation phase. In this case, subjects used stored idiothetic information in order to mentally estimate the length of the hypotenuse and calibrated such a distance according to the visual information provided by the environment. We suggest that this overshoot is a consequence of the relative shortening of distances induced by the wideness of the room subjects were travelling in. Indeed, context effect on size judgement is powerful enough to interfere even with estimation concerning our own body parts (Wapner et al. 1963). Judgement on both arm’s length and head width differs while standing close to or far away from a wall. Estimates produced with fingers or ear at just a few inches from the wall were significantly smaller than those produced at a 20-feet distance: subjective arm length and head width are relatively greater in an ‘open-extended’ than in a ‘close-confined’ spatial context.

Likewise, we suggest that in the present experiment distance estimation is the result of the interaction between information from idiothetic signals (that provide a correct estimate while blindfolded) and visual information on the surrounding space, which is available during the response. The lack of overshoot in the eye-closed condition highlights the fact that knowledge of the environment per se is not sufficient to affect stored idiothetic information. Actually, compared to the small room, in this larger environment the travelled distances were always greater. However, it seems unlikely that a non-specific increase in responses could explain the results observed in the blindfolded condition: had this been the case, we should assume that subjects matched the required distances by chance. The more appealing hypothesis still remains that in a sufficiently large environment idiothetic information allowed a correct estimate.

Even if vision could be misleading, its contribution remains crucial. Indeed, our data show that the brain can use idiothetic information in a sufficient but not entirely accurate way: we used triangles of different dimensions and found that the greater the stimulus, the larger the error, independently of both condition (eye closed/eye open response) and location (small/large room, see Fig. 2).

In conclusion, our brain can build an accurate representation of the space travelled during passive displacement along a complex trajectory on the basis of stored idiothetic information alone. This navigation-based representation is quite precise and can be properly used to perform the spatial inference required to solve a triangle completion task. The contribution of visual information to the mental processing required to estimate the novel distance is ambiguous. Although it proves to be crucial in a small environment, in a larger one it interferes, probably by inducing a misperception of the real length of the path travelled during response. Our data show that complex spatial abilities, such as those required in the present task, do not result from the simple integration of different sensory inputs, but are strongly affected by cognitive factors depending on the context in which the task is carried out.

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