VISUAL COGNITION, 2003, *10* (2), 157–199

''What is my avatar seeing?'': The coordination of ''out-of-body'' and ''embodied'' perspectives for scene recognition across views

Michel-Ange Amorim

Research Centre in Sport Sciences, University of Paris Sud–XI, France

Scene recognition across a perspective change typically exhibits viewpoint dependence. Accordingly, the more the orientation of the test viewpoint departs from that of the study viewpoint, the more time its takes and the less accurate observers are to recognize the spatial layout. Three experiments show that observers can take advantage of a virtual avatar that specifies their future ''embodied'' perspective on the visual scene. This ''out-of-body'' priming reduces or even abolishes viewpoint dependence for detecting a change in an object location when the environment is respectively unknown or familiar to the observer. Viewpoint dependence occurs when both the priming and primed viewpoints do not match. Changes to permanent extended structures (such as walls) or altered object-to-object spatial relations across viewpoint change are detrimental to viewpoint priming. A neurocognitive model describes the coordination of ''out-of-body'' and ''embodied'' perspectives relevant to social perception when understanding what another individual sees.

Inferring the direction in which another person is attending provides critical information for monitoring social interactions, for directing one's own attention, and assessing potential sources of threat (Haxby, Hoffman, & Gobbini, 2002). Nowadays 3D computer graphics tools are increasing the use of shared virtual environments populated with ''doppelgangers'' or ''avatars'' (Paniaras, 1997; Roehl, 1998). The most popular applications are telebusiness, collaborative work, and cooperative video games. The virtual characters are more than

---

Please address all correspondence to: M.-A. Amorim, Research Centre in Sports Sciences, Division STAPS, University of Paris Sud–XI, 91405 Orsay Cedex, France.

Email: michel-ange.amorim@staps.u-psud.fr

The author would like to thank Glyn Humphreys and two anonymous reviewers for their comments on a first draft of this paper, as well as Simon Lambrey for discussing the results of Experiment 2. Experiments 1 and 2 were performed at the LPPA—Collège de France—CNRS, Paris with the support of Alain Berthoz and Hans Müller-Gärtner, whereas Experiment 3 was conducted at the Division STAPS, University of Paris Sud–XI, Orsay.

http://www.tandf.co.uk/journals/pp/13506285.html DOI:10.1080/13506280244000078

puppets, since the observer may switch from an external or ‘‘out-of-body’’ perspective onto his/her avatar to an ‘‘embodied’’ perspective and see the synthetic world through the eyes of the avatar. Knowing when to switch from an ‘‘out-of-body’’ to an ‘‘embodied’’ perspective requires from the user to anticipate the content of the visual scene from an immersive perspective. The present study investigates the cognitive processes involved in the anticipation of the visual consequences of these perspective switches.

COORDINATING ‘‘OUT-OF-BODY’’ AND ‘‘EMBODIED’’ PERSPECTIVES: PUTATIVE BRAIN MECHANISMS

Understanding where another individual is directing attention involves the processing of various visual cues such as head and body posture orientation, as well as eye gaze signals. The processing of these different sources of information is a prerequisite for inferring the dispositions and intentions of other individuals, often referred as ‘‘social perception’’. Recent reviews of the neurophysiological and neuroimaging literature (Allison, Puce, & McCarthy, 2000; Haxby, Hoffman, & Gobbini, 2000, 2002) suggest that two functional brain systems act in concert during social perception. On the one hand, cells in the superior temporal sulcus (STS) region respond to the changeable aspects of social communication such as the perception of biological movement, including facial expression (eye and mouth movements), and movements of the whole body and hand. These movements must not necessarily be instantiated, since the presentation of still images with implied motion are sufficient to evoke a response (Allison et al., 2000). On the other hand, cells in the human fusiform gyrus (and primate inferior temporal cortex) mediate the extraction of invariant aspects of social perception, that is identity information. In addition, regions such as the superior bank of the superior temporal sulcus and the intraparietal sulcus have reciprocal connections that could mediate the transfer of information about gaze direction and head orientation to parietal neural systems for spatial attention (Haxby et al., 2002).

STS neurons are known to have their activity modulated by the sight of the head and/or body (Wachsmuth, Oram, & Perrett, 1994). More cells respond to the head in isolation than to a body without head, but the response to the whole body accumulates faster than the response to either part presented in isolation. A recent study by Jellema, Baker, Wicker, and Perrett (2000) has shown that a population of cells in the anterior part of the STS in the macaque monkey respond selectively to the sight of reaching but only when the agent performing the action is seen to be attending to the target position of the reaching. Accordingly, the coherence of face, eye gaze, and body posture information would be analysed in this brain region.

Understanding what another individual sees requires the coordination of ‘‘out-of-body’’ and ‘‘embodied’’ perspectives. Figure 1 offers a model of

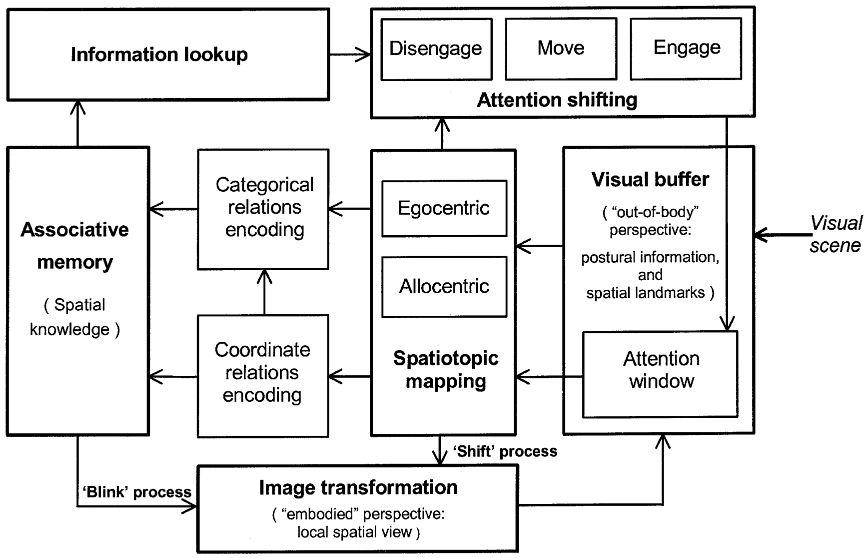


Figure 1. A neurocognitive model describing the processes supposedly engaged in the coordination of ''out-of-body'' and ''embodied'' perspectives.

hypothesized neurocognitive processes engaged in the construction of an egocentric or ''embodied'' view of space from the postural information and spatial landmarks available from the current exocentric or ''out-of-body'' perspective on the visual scene. This model is inspired from Kosslyn's (1991) theoretical approach on visuospatial cognition.

The ''spatiotopic mapping'' subsystem would be in charge of coordinating the processes engaged in the visual analysis of postural information (mentioned above) and those ''reading'' the spatial information available in the visual scene, transferred to the visual buffer (visual working memory). Statiotopic mapping is more or less equivalent to ''cognitive mapping'': a process ''composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls and decodes information about the relative locations and attributes of phenomena in the everyday spatial environment'' (Downs & Stea, 1973, p. 9). The information concerning real or imaginary locations can be specified either relatively to the viewer (egocentric mapping, e.g., ''The computer is 50 cm away on my left side'') or to a part of the environment, e.g., an object or a place (allocentric mapping, e.g., ''I am in front of the building''). The cognitive demand of the task will vary depending on the frame of reference used to read the incoming spatial information temporarily stored in the visual buffer. It is well established that object-centred (allocentric) and viewer-centred (egocentric) frames of reference are not equivalent in their use (e.g., Amorim & Stucchi, 1997; Presson, 1982; Wraga, Creem, & Proffitt, 2000). Afterwards, information on locations is encoded either in distance, direction, and orientation coordinates (coordinate relations encoding), or into categories (categorical relations encoding) like ‘‘connected to’’, ‘‘left to’’, ‘‘under’’, ‘‘above’’ (Carlson-Radvansky & Irwin, 1993).

This coded spatial information then goes in the associative memory where it is matched to stored information about the location, name, and functionality of the other object(s) contained in the visual scene. The hippocampus would play a dominant role in the elaboration of a spatial knowledge from associative memory. Spatial view cells were found in the primate hippocampus (Rolls, 1999) that are tuned to respond to a view of space ‘‘out there’’, not to the place where the monkey is, contrary to the rat hippocampus ‘‘place cells’’. Rolls proposed that the spatial representation provided by primate spatial view cells would be part of a memory system involved in memories of particular events or episodes, for example, of where in an environment an object was. Functional imaging techniques (Aguirre & D’Esposito, 1997) have shown a physiological dissociation between the brain processes associated with landmark recognition (occipito-temporal ventral stream) and those associated with knowledge of the relative positions of landmarks (occipito-parietal dorsal stream). One might suggest that hippocampal cells serve as an indexing system for associating information spreading through both the dorsal and ventral visual streams. Recent brain imagining studies provide data consistent with this hypothesis: Retrieving ‘‘object’’ landmarks after mental navigation along a memorized route involves both the hippocampal and parahippocampal regions (Burgess, Maguire, Spiers, & O’Keefe, 2001; Mellet el., 2000). Rolls and O’Mara (1995) argue that the representation of space provided by hippocampal view-responsive neurons may be useful in forming memories of spatial environments on the basis of both egocentric and allocentric frames of references, for example, of where an object has been seen and of where the monkey is as defined by seen views. De Araujo, Rolls, and Stringer (2001) recently proposed that the apparent discrepancy between rat ‘‘place cells’’ and primate ‘‘spatial view cells’’ in the hippocampus is due to a difference in the size of the cells visual receptive fields. They tested a computational model offering a common hippocampal mechanism operating with different visual receptive fields sizes (270° for rodents and 30° for primates) that elegantly accounts for some of the visual properties of both place cells and spatial view cells.

The posterior parietal cortex begins the transformation of retinotopic visual information into higher-order reference frames. It participates to egocentric coding of locations on the basis of eye position as well as the orientation of the head on the body. Besides containing a multimodal and multiple coordinate representation of space, the posterior parietal cortex also contains circuitries that appear to be important for shifting attention, stimulus selection, and movement planning (Andersen, Snyder, Bradley, & Xing, 1997). Thus, this brain structure seems a good candidate for homing the ''information lookup'' system described in Figure 1.

Anticipating the new perspective on the visual scene might be the result of a series of rotations and translations of the initial scene, or of an image generation process equivalent to that Huttenlocher and Presson (1973) referred to as a ''regenerative strategy'' (p. 295) in perspective-taking tasks. These different processes correspond respectively to the ''shift'' versus ''blink'' transformations on mental image investigated by Kosslyn (1980, 1987). ''Shift transformations involve altering an existing image, whereas blink transformations involve letting an initial image fade and then accessing stored information and generating a new image'' (Kosslyn, 1987, p. 166). In the latter case, an ''embodied'' spatial view would be instantiated from the spatial knowledge. These processes are different both in terms of cognitive resources and mental chronometry. The higher processing load for blink transformation over shift transformation is well established (Kerr, 1993; Kosslyn, 1980). However, both image transformations generally tend to increase response time and errors proportionally to the amount of transformation (e.g., Kosslyn, Ball, & Reiser, 1978 and Pinker, 1980 for scanned distance in 2D and 3D respectively; Shepard, & Metzler, 1971 for mental rotation; and Roth & Kosslyn, 1988 for 3D image generation). Finally, image transformations are affected by the frames of references tapped. For example, an advantage in both response latency and accuracy for viewer rotation compared to rotation of the objects themselves is generally observed when updating the positions of objects in space after imagined self rotation (Amorim & Stucchi, 1997; Presson, 1982; Wraga et al., 2000).

Although no brain imaging examined the neurofunctional basis of the anticipation of visual content of viewpoint change from postural information, a recent fMRI study by Creem, Downs, and colleagues (2001a) on imagined self rotation provides results compatible with the hypothesized brain mechanisms just mentioned before. These authors used fMRI to identify the neural substrates involved in updating the positions of several external objects relative to oneself after explicit imagined movement of the body to a new perspective. The participants were shown a picture of a diamond-shaped array of four objects (bed, hammer, teapot, car) and memorized the positions of the objects. They were told to think of themselves lying down in the middle of the array so that the objects were perceived as being in front of their bodies, in back, on the left, and on the right. After a learning period, the display was removed and the rotation task was performed from memory. On each trial, participants listened to a degree to imagine rotating, and a position in the array. They imagined rotating clockwise inside the object array following verbal instructions on the rotation amplitude and position of interest in the array (i.e., ''90 degrees, what is on the right?''). Response was recorded from pressing a button corresponding to the name of the object. Participants imagined themselves back in their original position at the beginning of each trial. The authors obtained results similar to the behavioural results for the viewer task reported in Wraga et al. (2000, Exp. 2) in which participants stood inside an array of four objects and imagined rotating themselves in a manner similar to that of the present experiment. However, a marked distinction between the latter study and that of Creem, Downs, and colleagues (2001a) is that in all of Wraga et al.'s (2000) experiments participants stood facing four objects in a diamond-shaped array *placed on pedestals on the floor*. Looking to a survey picture of an array of objects facilitates the visual evocation of the body posture fitting inside the array from an ''out-of-body'' perspective, whereas facing a configuration of objects standing on pedestals induces a more immersive or ''embodied'' perspective. This difference in protocol is of special interest since Creem et al.'s (2001a) experimental setup might have engaged processes similar to those illustrated in Figure 1. These authors found the activation of a network including superior parietal, premotor, and secondary visual areas. The left superior parietal lobule was the largest area of activation observed, a part of the dorsal visual processing stream, which transforms visual information using an egocentric coordinate system as previously mentioned. Interestingly, Creem et al. (2001a) mention that the left hemisphere activation they observed supports Zacks, Rypma, Gabrieli, Tversky, and Glover (1999) finding of an activity in the left parietal-temporal-occipital junction in a task that required a left–right judgement about a human figure from the figure's perspective. This is another clue in favour of the evocation of an ''out-of-body'' perspective in their experiment. Several regions of activation associated with motor processing also emerged (such as the premotor area and subcortically the cerebellum). Finally, activation was found in areas known to be associated with object perception (right fusiform gyrus) and spatial memory (left parahippocampal gyrus). This last finding is compatible with previous work suggesting that the left hippocampus and surrounding regions are involved in tasks that coordinate the relation between whole-body movements and locations in the environment, such as in mental navigation along memorized routes (Aguirre, Detre, Alsop, & D'Esposito, 1996; Ghaem et al., 1997) and in the retrieval of contextual memories more generally (Burgess et al., 2001).

Most of the neurofunctional regions activated in Creem et al.'s (2001a) perspective change experiment are compatible with the model illustrated in Figure 1 describing the hypothetical processes involved in anticipating the visual consequences of viewpoint change (''embodied'' perspective) from visually available postural information (''out-of-body'' perspective). However, one should keep in mind that in their experimental paradigm the postural information was at best implicit but not visually available. More generally, there is no behavioural data comparing the consequences of advance postural information, in perspective-taking performance, to a condition where no advance information is provided on future viewpoint. In the present study, a virtual character (a harlequin) was used to specify observer's future viewpoint in a 3D computer graphics environment. The assumption was that the advance information provided by this avatar under an ‘‘out-of-body’’ perspective would prime the perspective change and improve spatial judgements from the new perspective.

‘‘Out-of-body’’ imagery perspective, although unusual, can be evoked spontaneously by the brain under various circumstances. However, the coordination of out-of-body and embodied perspectives was seldom investigated experimentally. The next section will illustrate how perspective-taking experiments may help making sense of spontaneous imagery data.

‘‘OUT-OF-BODY’’ IMAGERY PERSPECTIVE: FROM ‘‘EXPERIENCE’’ TO ‘‘EXPERIMENT’’

Many surveys suggest that spontaneous ‘‘out-of-body experience’’ (OBE) is a normal, although unusual event associated with ecsomatic or ‘‘out-of-body’’ perspective change (Alvarado, 1992; Irwin, 1981; Tobacyk & Mitchell, 1987). OBE occurs most frequently (78%) during a relaxed physical state (Twemlow et al., 1982), like dreaming, or during the imagery just preceding sleep (Mavromatis, 1987) or awakening (Glicksohn, 1989); and more rarely during traumatic experiences such as near-death (10%) or heart attack (5%) episodes (Gabbard, Twemlow, & Jones, 1981; Twemlow, Gabbard, & Jones, 1982). OBE would be a response from the brain to the reduced somatic information during extreme relaxation conditions, or a denial of death in the case of traumatic episodes (Ehrenwald, 1974), in an attempt to restore the self and body integrity. Along those lines, a duplicate of the body image or ‘‘doppelganger’’ imagery is reported in 68% of OBE (Twemlow et al., 1982).

This ‘‘out-of-body’’ perspective on oneself corresponds to the ‘‘observer’’ perspective adopted by subjects when recalling events (Lorenz & Neisser, 1985; Robinson & Swanson, 1993). The ‘‘field perspective’’ or ‘‘embodied’’ corresponds to the initial field-of-view on the environment, whereas the ‘‘observer perspective’’ or ‘‘out-of-body’’ imagery would be ‘‘seeing oneself’’ from the outside as an external observer standing back with respect to the visual scene. Recalling anxiety-provoking social situations (Coles, Turk, Heimberg, & Fresco, 2001; Wells, Clark, & Ahmad, 1998) or situations of high-public self awareness (Sugiura, 1996) favour the spontaneous evocation of an ‘‘observer’’ or ‘‘out-of-body’’ imagery rather than a ‘‘field’’ or ‘‘embodied’’ perspective. Finally, the fact that individuals who have OBEs tend to adopt an observer perspective while recalling dream content (Blackmore, 1987; Irwin, 1986) and that they show superior visuospatial skills than controls (Cook & Irwin, 1983) would suggest that their proneness to OBE may reflect a specific cognitive style regarding perspective-taking ability (see General Discussion).

Interestingly, shortly after Piaget and Inhelder’s (1956) pioneering work in children, perspective-taking referred to the ‘‘ability to imagine or to represent how objects look relative to one another from *another person’s point of view*’’

(Cox, 1977, 254). In the original studies, this ''person'' would usually be a doll (Fishbein, Lewis, & Keiffer, 1972) and sometimes even an animal (Huttenlocher & Presson, 1973). It is only since Huttenlocher and Presson (1979) that studies have examined performance when subjects are surrounded by objects and have to imagine their *own perspective change* from an embodied perspective (for a review, Wraga, Creem, & Proffitt, 1999). Usually, the to-be-imagined perspective change would involve a self rotation of the observer, or a translation toward a new vantage point, and the task would be pointing to target objects. The strong assumption behind these studies is that subjects comply with instructions respectfully. Accordingly, variations of reaction time and error that depend on angular difference between real and imagined perspective (e.g., performance typically degrades for increasing angles) is supposed to reflect a mental transformation of the visual scene content from an embodied perspective. However, another strategy is also possible: Namely that the subject sends an imaginary ''doppelganger'' to the new station point, observe him/her pointing to the target, and replicate his/her posture. Juurmaa and Lehtinen-Railo (1994) reported, in their perspective change study, that half of the subjects used this ''doppelganger'' strategy in order to keep their own physical location in mind while they shifted imaginally to the new station. Then, the reaction time and error patterns would reflect imagined spatial transformation of one's body, more like in Parsons' (1987) study, in order to align the real and the imagined body postures.

In order to examine the differential effect of ''out-of-body'' and ''embodied'' imagery perspectives on the access to spatial knowledge issued from a desktop virtual environment, Amorim, Trumbore, and Chogyen (2000) used a modified version of the experimental paradigm devised by Lea (1975) to perform a chronometric analysis of the method of loci. The method of loci (Yates, 1966) is a mnemonic which involves forming an image of a familiar room or other space, and imaging the to-be-remembered objects or items each in a specific location. At the time of recall, the locations (loci) in the image are inspected and the items incorporated in them are identified. Up to 40 items may be perfectly retrieved after such a mental travel (Crovitz, 1971; Ross & Lawrence, 1968). In Amorim et al. (2000) study, ''locus'' referred to ''vantage point'' rather than to the *identity* of the locus as was the case in Lea's (1975) study. Observers initially learned the location of unfamiliar objects in a virtual environment. Then, from a starting locus (vantage point), they were asked to scan mentally the emptied room in order to retrieve either the *n*th *locus* or the *n*th *item*. The task was performed either from the centre of the room using an ''embodied'' imagery, or from its periphery while imagining seeing themselves from an ''out-of-body'' perspective. Lea found higher response times when looking for the *n*th item rather than the *n*th locus, suggesting that ''location'' information must be accessed before retrieving its associated ''object''. Amorim et al. (2000) found the same difference mostly when an ''embodied'' perspective was used to explore the environment. They proposed that mental exploration of the visual scene from an ''out-of-body'' perceptive involves a scanning process whose rate of processing is faster than the process used to generate the missing visual world from ''embodied'' perspectives.

The present study will examine the effects of advance information about future perspective, provided by a virtual avatar of the observer, on scene recognition across views. The processes involved in the priming of ''embodied'' perspective from an ''out-of-body'' imagery will be addressed in the next section.

VIEWPOINT DEPENDENCE IN SCENE RECOGNITION: PRE VS. POSTPROCESSING

Recent studies on scene recognition across views have found that recognition of spatial layouts containing several objects seems to be view-dependent (Christou & Bülthoff, 1999; Diwadkar & McNamara, 1997; Simons & Wang, 1998; Wang & Simons, 1999). Typically, the time it takes to decide from a new view that the environment layout is the same increases linearly with the angular difference between the two viewpoints (Shelton & McNamara, 1997), as if an image transformation process such as mental rotation (Shepard & Metzler, 1971) was used to match both the memorized and actual views. Similarly, a decrease in response accuracy often accompanies the increased angular disparity between actual and imagined perspectives (Easton & Scholl, 1995; Farrell & Robertson, 1998).

The absence of an effect of viewpoint angular disparity (whether linear or not) on spatial judgements would be suggestive of viewpoint independence. If viewpoint dependence reflects the use of an *a posteriori* image transformation process, i.e., from the new perspective on the visual scene, then viewpoint independence could be achieved by providing advance information on observer's future orientation in order to perform this transformation *a priori*, that is before the perspective change. Two series of mental imagery experiments, one on mental rotation and the other on mental scanning, show results compatible with these predictions regarding the effect of advance information on scene recognition.

On the one hand, Cooper and Shepard (1973) showed that providing both an identity and orientation information (but not either alone) was sufficient to ''prepare'' for mental rotation. The task was to identify if alphanumeric characters, presented in various orientations in the picture-plane (for 0° to 300° in steps of 60°), were mirror-reversed or not. In their ''separate identity and orientation'' condition, the alphanumeric character was first presented (identity information) in its normal upright orientation for 2000 ms. Then, it was followed by an arrow (orientation information) under the same orientation as the subsequent presentation of the rotated test character. The presentation time of the arrow was either 100, 400, 700, or 1000 ms. Interestingly, the increase in reaction time to the test character with its departure from upright, suggestive of mental rotation, disappeared only when the orientation cue lasted 1000 ms. This result suggests that mental rotation, whether pre- or poststimulus (the stimulus being the rotated test character), can be performed under the provision of a minimal processing time cost.

On the other hand, experiments on mental scanning of either 2D (Kosslyn et al., 1978) or 3D (Pinker, 1980) remembered configurations have shown a linear relation between scanning distance and reaction time. These findings are consistent with the hypothesis that mental images preserve information about the spatial and perspective properties of objects and visual scenes. Notably, Finke and Pinker (1983) showed that for 2D mental images, priming scanning direction made the linear dependence of reaction on scanned distance vanish. The task was to observe a dot pattern, followed by an arrow, and to indicate whether the arrow was pointing at any of the previously seen dots. When no advance information was provided about the arrow's location, response times increased linearly with increasing arrow-dot distance. However, when a cue for the arrow's location was presented 2 s beforehand, reaction times were unrelated to scanned distance. Interestingly, if instead of cueing the arrow location 2 s, after the dot pattern was removed a blank field was presented for 1 s, followed by the arrow location cue for 1 s, the linear function of reaction times was observed only for the furthest arrow-dot distances. This suggests that the 1 s presentation of advance information allowed for advance image scanning of a much smaller image area than the 2 s cue display. Along the same lines as Cooper and Shepard (1973) findings on the effect of advance information on mental rotation, the results of Finke and Pinker (1983) suggest that performing mental scanning from advance information requires a minimal processing charge.

In summary, the results provided by these two series of studies agree with the prediction that if advance information on future viewpoint is available, viewpoint dependence of perspective change would diminish, provided that this advance information stays enough time to anticipate what the future perspective on the visual scene will be. This assumption was tested in the present study. Advance information was provided in the form of a harlequin to be interpreted as the avatar of the observer, i.e., his/her virtual representation. On the one hand, by priming the future viewpoint this initial ''out-of-body'' perspective was expected to increase globally both response speed and accuracy for spatial judgments performed from the new viewpoint, such as detecting a change in an object location. On the other hand, viewpoint dependence was expected to diminish, provided that the ''out-of-body'' perspective stays long enough and that the available spatial frames of reference are not ambiguous. Along those lines, anticipating viewpoint change in an architectural environment would be easier than inside an array of objects, because it would provide a more impressive sense of space due to its permanent nature. Perspective change inside an array of objects located in an open-field implies a modification of self-to-object reference frames while supposing object-to-object relations invariant across viewpoint change. When the objects are located in an architectural environment, redundant spatial information is provided by additional frames of reference, namely self-to-environment and object-to-environment. The environmental frame of reference is specified by structures such as walls, stairs, supposedly more stable and permanent spatially than movable objects such as furniture. Gouteux and Spelke (2001) provided recent findings on children and adults consistent with the prediction that the presence of an environmental frame of reference would facilitate spatial judgements following a viewpoint change. They showed that early developing navigational abilities depend on a mechanism that is sensitive to the shape of the permanent extended surface layout, but that is not sensitive to geometric or nongeometric properties of objects in the layout. In addition, movable objects (whatever their size) are encoded differently from nonmovable extended surfaces (Wang & Spelke, 2000).

Let's consider that one must detect that a target object changed its position after a viewpoint change. If advance information allows to anticipate the new viewpoint, then the comparison between the anticipated and the actual (new) viewpoint is direct. Accordingly, detection of a change in ''object location'' would be independent of angular disparity between the initial and final viewpoints. In contrast, if the new viewpoint cannot be anticipated, an image transformation process must be triggered to match the visual scene from both the memorized (initial) and the actual (final) viewpoints. Similarly, in a task requiring to perform a ''self-location'' judgement to detect if the new viewpoint matches the primed (expected) viewpoint, if the new viewpoint was correctly primed reaction time should be fast and independent from angular disparity between viewpoints. In contrast, if the new viewpoint was not correctly primed, a mental rotation process would be used to compare both the current and primed viewpoints, and viewpoint dependence would come back. These results are expected under the assumption that object-to-object and/or object-to-environment spatial relations are kept invariant across viewpoints. For example, if a change in object-to-object spatial relations occurs during the viewpoint change, while assumed to be a stable frame of reference, such an incongruence in the visual scene would interfere with the ''self-location'' judgement and favour viewpoint dependence.

In summary, if enough time is allowed during ''out-of-body'' priming to anticipate a new viewpoint, assuming that the primed viewpoint corresponds to the new viewpoint, then spatial judgements performed from the new viewpoint should be independent from angular disparity between viewpoints. In other words viewpoint independence of perspective change would prevail. In contrast, if the new viewpoint was either not correctly primed or not primed at all, then a mental rotation mental process would be necessary to compare spatial information from both the memorized and new viewpoints, thereby introducing dependence in viewpoint in both response time and accuracy for spatial judgements. Three experiments were conducted in order to test these different predictions.

In Experiment 1, observers detected if a target object changed its position in the visual scene after a viewpoint change either after being primed on their next vantage point via a virtual avatar of the observer (''doppelganger''), or without such an ''out-of-body'' priming. In order to test if visual distortions, due to a difference between observer's ''real'' and ''virtual'' field-of-view (FOV) on the visual scene, impair spatial judgements participants were divided in two groups. One group performed the task facing a large projection screen (under matched real and virtual FOVs), whereas the other observers faced a computer screen (nonmatched FOVs). In Experiment 2, in addition to the detection of a change in ''object location'', in another condition observers were required to detect a change in expected ''self location'', that is between priming and primed viewpoints. Depending on trials, a local incongruence (in object-to-object spatial relations) was introduced across viewpoints in the visual scene in order to test if the viewpoint anticipation could be performed on the basis of the environmental frame of reference alone. Finally, in the Experiment 3, performance in detecting a change in ''object location'' or in expected ''self location'' was compared in two different environments, namely an architectural environment and an array of objects (furniture). The contribution of the environmental frame of reference to the priming of viewpoint change was possible by comparing performance in both environments.

EXPERIMENT 1

The use of virtual environments for the study of spatial cognition (Loomis, Blascovich, & Beall, 1999; Péruch & Gaunet, 1998) is increasingly popular for the experimental conditions are well-defined and can easily be reproduced. However, the effect of ''field of view'' (FOV) on spatial orientation performance is a recurrent issue in the virtual reality literature (Cutting, 1997; Psotka, Lewis, & King, 1998; Wickens & Backer, 1995), especially considering the visual distortions occurring when the simulated (geometric) and physical (absolute) FOVs are not matched. Figure 2 illustrates the difference between the physical (real) FOV defined by the angle (horizontal and vertical) under which the observer sees the display, and the simulated (virtual) FOV generated by the computer, defined by the angle (horizontal and vertical) under which the virtual eyepoint (camera) sees the simulated environment.

In order to test if observers can build similar spatial knowledge for the virtual environment although the simulated and physical FOVs may not match, some of the observers performed the experiment under a nonmatched FOV condition (physical FOV = 61% of the simulated FOV) using a monitor, and the others with a matched FOV using a large projection screen (Figure 2).

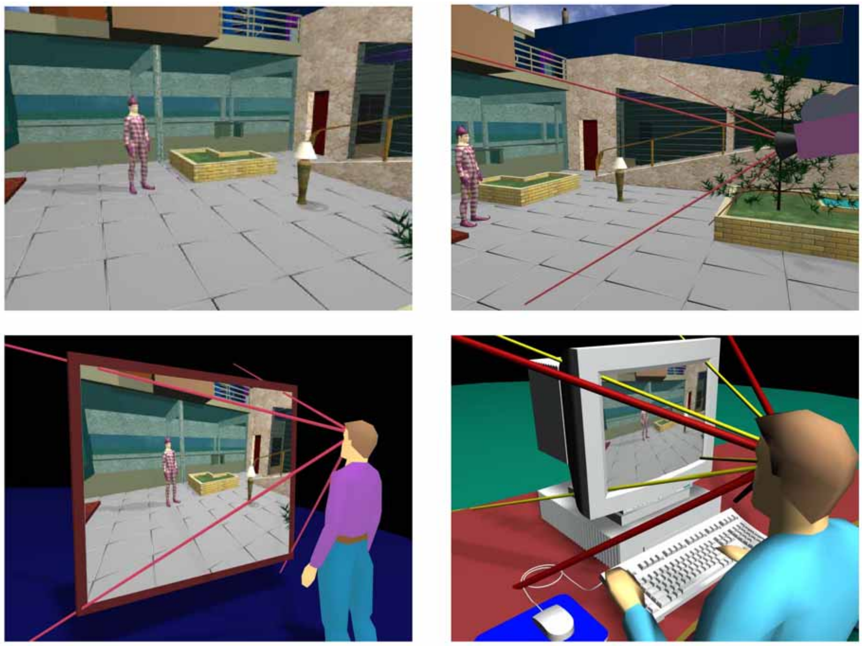


Figure 2. The difference between the physical (real) and the simulated (virtual) field-of-view (FOV) is illustrated. Upper left: An example of initial viewpoint in the virtual environment. Upper right: The angle (horizontal and vertical) under which the virtual eyepoint (camera), used to generate the upper left stimulus, sees the simulated environment. Lower left: A ''matched FOV'' condition; the physical FOV under which the observer sees the display coincides with the simulated FOV generated by the computer in the upper right panel. Lower right: The physical FOV under which the observer sees the display (thin lines) corresponds to 61% of the simulated FOV (thick lines). (To view this figure in colour, please see the online issue of the journal.)

In this experiment, observers memorized a visual scene from an initial vantage point and detected if a target object changed its position in the environment after a viewpoint change. Depending on the condition, observers were either primed on their new vantage point via a ''doppelganger'' (virtual avatar) to whom they identified themselves, or had no such ''out-of-body'' priming.

Method

Participants. Twenty-six individuals aged between 23 and 49 participated in this experiment, fourteen in a nonmatched FOV condition, and twelve with a matched FOV.

Stimuli and apparatus. The virtual model of an architectural environment as well as the picture stimuli were generated using 3DStudio MAX® and

Character Studio® with a 24-mm lens ($\approx 74 \times 59^\circ$ simulated FOV). The experiment was generated and monitored using ERTS-VIPL™, a PC-compatible software package that allows development and performance of psychological experiments (Beringer, 1994a, 1994b).

The different virtual camera and target (a lamp standing on the floor) positions used to generate the stimuli are illustrated in Figure 3. The target positions were distributed on a circle of 1.80 m radius, every 45°. A harlequin was used to indicate observers' next vantage point in the ''out-of-body'' priming trials. All the cameras were positioned at the harlequin's eye level, and focused on a point located in the centre of the lamp configuration. All the participants were unfamiliar with the environment and never saw a survey perspective of it.

Procedure. The observer memorized the position of the lamp from an initial viewpoint displayed for 5 s, followed automatically by a new viewpoint on the visual scene. The task was to indicate by a keypress if the lamp changed its position in the scene, when observed from a new viewpoint. Depending on the condition, the new vantage point was primed via a harlequin or not primed (Figures 4 and 5).

Figure 3. Survey perspective on the virtual architectural environment used in the experiments. The camera and target (lamp) positions used to generate the stimuli are presented. A harlequin location is instantiated. (To view this figure in colour, please see the online issue of the journal.)

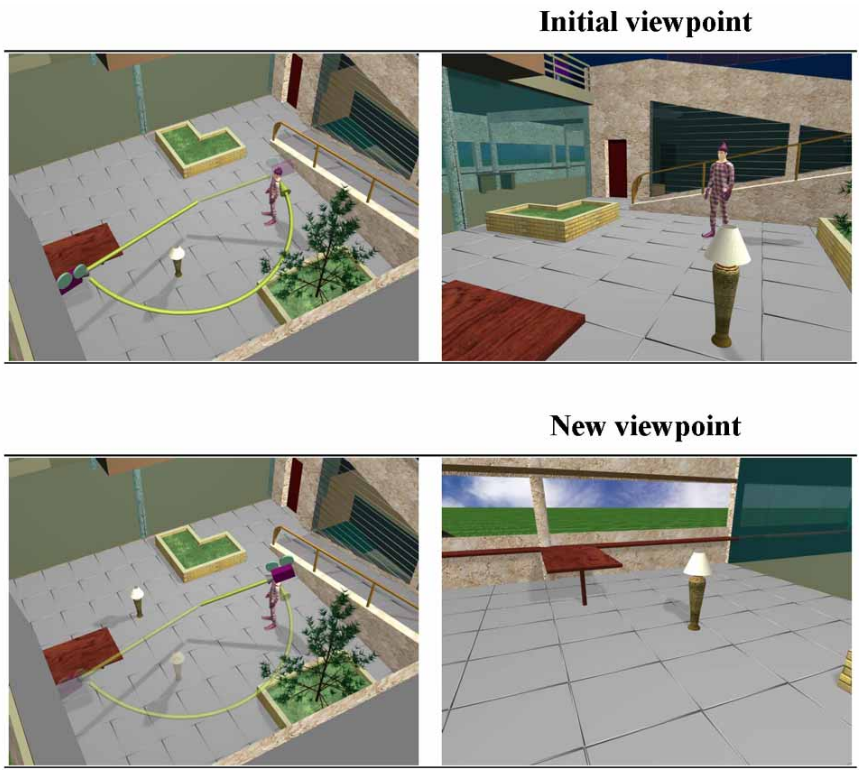


Figure 4. Description of how an ''out-of-body'' priming trial, in which the target changes its position across views, is generated (Experiments 1–3). Upper left: The angular difference (135°) between lines of sight of the camera used to generate the initial viewpoint stimulus illustrated in the upper right panel, and the (initially invisible) camera used for the new viewpoint, as well as the target position. Lower left: The new target position (previous target position is made invisible) as well as the camera used to generate the new viewpoint in the lower right panel. (To view this figure in colour, please see the online issue of the journal.)

A computer keyboard was used to record responses. Participants triggered each trial by pressing the space bar. On half of the trials (50% of the primed trials, and 50% of the nonprimed), the lamp position was changed across viewpoint change; it moved to its second clockwise or counterclockwise next possible position (Figure 4). 32 viewpoint change pairs were used. The viewing positions were randomly chosen among those possible (Figure 3), with the constraints that the lamp should always be clearly visible, and that the viewpoint change was either 45°, 135° (irrespective of direction), or 180°. The stimuli pairs were displayed in pseudorandom order, different for each participant. Participants underwent 32 trials without feedback, preceded by 4 training trials not included in the data analysis.

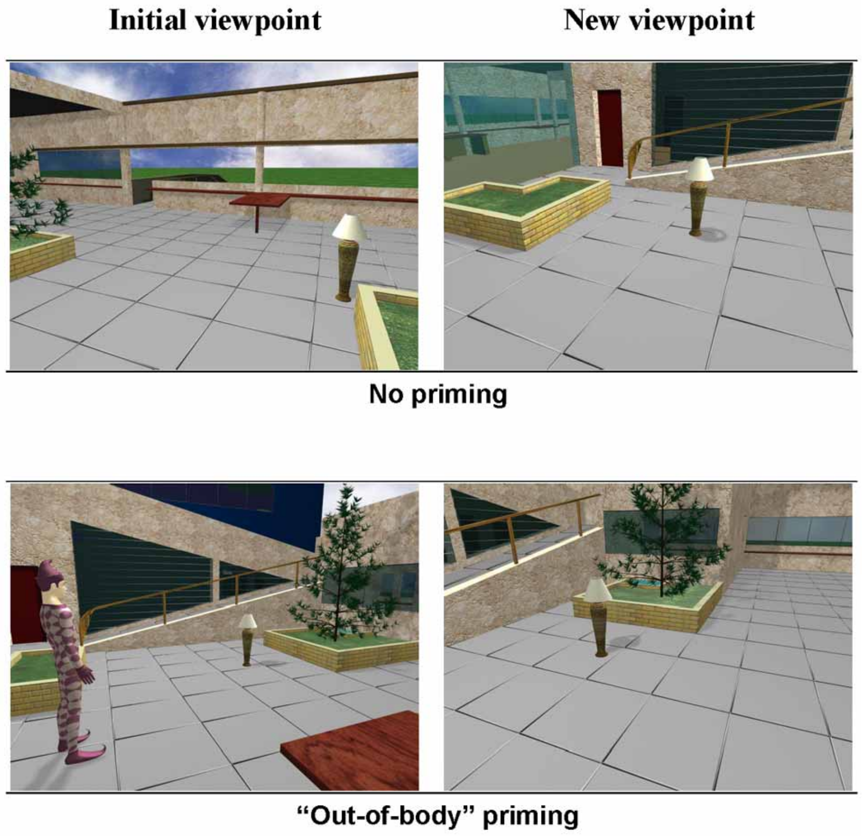


Figure 5. Illustration of the ''object location'' condition (Experiments 1–3). After examining an initial view for 5 s, observers switched perspective and indicated from the new viewpoint if the lamp had changed its position. Depending on the condition, observers could be primed by the harlequin occupying their future self-location (''out-of-body'' priming) or not primed (no priming). Upper views: the target changed its position after a 180° viewpoint change. Lower views: During this 45° primed viewpoint change the target stays at the same position in the environment. (To view this figure in colour, please see the online issue of the journal.)

Results and discussion

A repeated measures ANOVA with priming condition (''out-of-body'' priming vs. none) and viewpoint angular difference (45°, 135° vs. 180°) as within-subjects variables and FOV (matched vs. nonmatched simulated and physical FOVs) as between-subjects variable was conducted. Results indicate that observers responded significantly more rapidly, $F(1, 24) = 14.35$, $p < .001$, and accurately, $F(1, 24) = 12.22$, $p < .01$, after ''out-of-body'' priming than without. There was a significant increase in reaction time, $F(2, 48) = 20.50$, $p < .0001$, with angular difference in viewpoint change paralleled by a significant decrease in accuracy, $F(2, 48) = 18.59$, $p < .0001$. The effect of priming varied with viewpoint angular difference, $F(2, 48) = 3.78$, $p < .05$, for response accuracy but not for reaction time ($F < 1.03$). Table 1 shows the mean values describing the effect of viewpoint angular difference on response time and accuracy for each priming condition.

Finally, there was no difference between matched vs. nonmatched FOV conditions, neither for reaction time ($F < 1$) nor for response accuracy ($F < 1$). This absence of an effect of the FOV manipulation on spatial performance suggests that observers can acquire spatial knowledge of a three-dimensional virtual environment from a desktop display although their actual (physical) field of view does not match the (simulated) one used to generate the visual scene. The fact that the brain can cope with visual distortion induced by nonmatched field of views suggests that some flexibility exists in the visual buffer for matching actual and imagined views (cf. Figure 1).

The other results indicate that observers took advantage of the ''out-of-body'' priming of their future vantage point for detecting a change in an object location across views. However, it still remains possible that observers did not use the harlequin to fully anticipate the visual consequences of the subsequent perspective change by encoding coordinate spatial relations. Instead, priming might have allowed them to encode object position relative to their next orientation using a categorical encoding of spatial relations, e.g., ''the lamp will be at my left side'' or ''right side'' (cf. Figure 1). Therefore, in Experiment 2, a new task was devised in order to force observers anticipate the visual consequences of viewpoint change from the postural information provided by their avatar, i.e., ''out-of-body'' priming.

TABLE 1
Mean (±*SE*) effect of viewpoint angular difference on response time and accuracy for each priming condition (Experiment 1)

	Reaction time (ms)		*% correct*	
	''Out-of-body'' priming	*No priming*	*''Out-of-body'' priming*	*No priming*
45°	2635 (236)	2937 (263)	92.79 (1.69)	90.87 (2.21)
135°	3019 (285)	3571 (312)	85.58 (3.89)	63.46 (5.81)
180°	3579 (300)	3707 (282)	78.85 (3.52)	66.35 (5.43)
	2967 (276)	3288 (289)	85.74 (3.37)	73.56 (5.34)

EXPERIMENT 2

Experiment 1 provided evidence suggesting that ''out-of-body'' priming of perspective change improves subsequent detection of a change in an object location in a three-dimensional virtual environment. Due to an insufficient number of data points relative to the angular difference in viewpoint manipulation, it was not possible to furnish a conclusion concerning the effect of priming on viewpoint dependence. Therefore, in Experiment 2, a larger palette of angular differences was tested using the same ''object location'' task as in Experiment 1. A ''self-location'' task was also added in which observers were required to indicate if the new viewpoint was the one they expected, according to the ''out-of-body'' priming. Thereby, attention was redirected toward anticipating the visual consequences of perspective change. In order to study the effect of viewpoint priming on ''self location'', performance following correct and incorrect viewpoint primes was compared.

Another experimental manipulation tested if viewpoint anticipation was performed on the basis of the environmental frame of reference in a global way, that is from the directions specified by the walls, or if the initial spatial relationship between the environment and the objects it contains was included. Therefore, an outstanding object (the lamp used in the ''object location'' condition) changed its position across viewpoint change on half of the ''self-location'' trials, although observers were informed that this would happen and therefore the object should be ignored. This manipulation was inspired from the work of Christou, Bosco, and Bülthoff (1999) studying whether contextual information regarding an observer's location within a familiar scene (a 3D virtual living room) could influence the identification of objects. They showed that after familiarization of objects within the virtual room, the presence of the room during identification reduced errors as compared to objects shown in isolation. A control experiment, in which the orientation of the objects with respect to the room was randomly varied, tested the hypothesis that the reduction in error was attributed to the provision of a consistent reference frame by the room. Results showed that recognition accuracy dropped significantly in this case because the observer's relative orientation with respect to the objects could not be derived from the room. In summary, Christou et al. (1999) suggest that object identification can be aided by knowledge of where we are in space and in which direction we are looking.

Finally, in contrast to Experiment 1, in order to minimize the fact that viewpoint dependence may be due to unfamiliarity with the environment, observers were displayed a circular tour in the environment before the experiment started.

Method

Participants. Twenty-four individuals aged between 18 and 56 took part in this experiment. None of them had participated in the previous experiment.

Stimuli and apparatus. The materials were identical to those in Experiment 1; however, due to the absence of an effect of matched vs. nonmatched simulated and physical FOVs, this experiment was conducted using a monitor. The virtual environment was the same as before, but two new sets of 32 stimuli pairs were generated, one for the ''object location'' condition and the other for ''self location''. In addition, a video clip was generated showing a continuous 360° clockwise tour in the environment passing through each of the (invisible) far camera positions (Figure 3), without any lamp visible.

Procedure and design. Before the experiment started, observers were displayed five times a 360° tour in the virtual environment. The same procedure as in Experiment 1 was applied. In the ''object location'' condition, observers indicated if the target object (the lamp) changed its position during perspective change, with or without being primed on the new viewpoint (Figure 5). In the ''self-location'' condition, observers indicated if the next viewpoint was the one they expected according to ''out-of-body'' priming, irrespective of any change in the lamp position (Figure 6). On half of the trials, the new viewpoint was the one primed, whereas on the other half it corresponded to the left or right camera 45° away from the primed viewpoint (Figure 3 and 6). Therefore, the task was to judge if the new viewpoint was identical to the one adopted (primed) by the harlequin; which was the case in 50% of the trials. However, observers were explicitly informed to ignore the lamp in the ''self-location'' condition: Its position would change on half of the trials (incongruent scenes) and not in the other half (congruent scenes), for both correctly and incorrectly primed viewpoints.

In both the ''object-'' and ''self-location'' conditions, the amplitude of perspective change varied between 0° and 180° irrespective of direction, in steps of 45°. Four training trials, not included in the data analysis, preceded each block.

For the ''object location'' condition, the following factors were treated within-subject: Priming (''out-of-body'' priming vs. no priming), and viewpoint angular difference (0°, 45°, 90°, 135°, vs. 180°). For the ''self-location'' condition, the following factors were treated within-subject: Priming (correct vs. incorrect viewpoint primes), scene congruence (congruent or incongruent scenes), and viewpoint angular difference (0°, 45°, 90°, 135°, vs. 180°). Half of the observers underwent the ''object location'' condition first, in one block, and

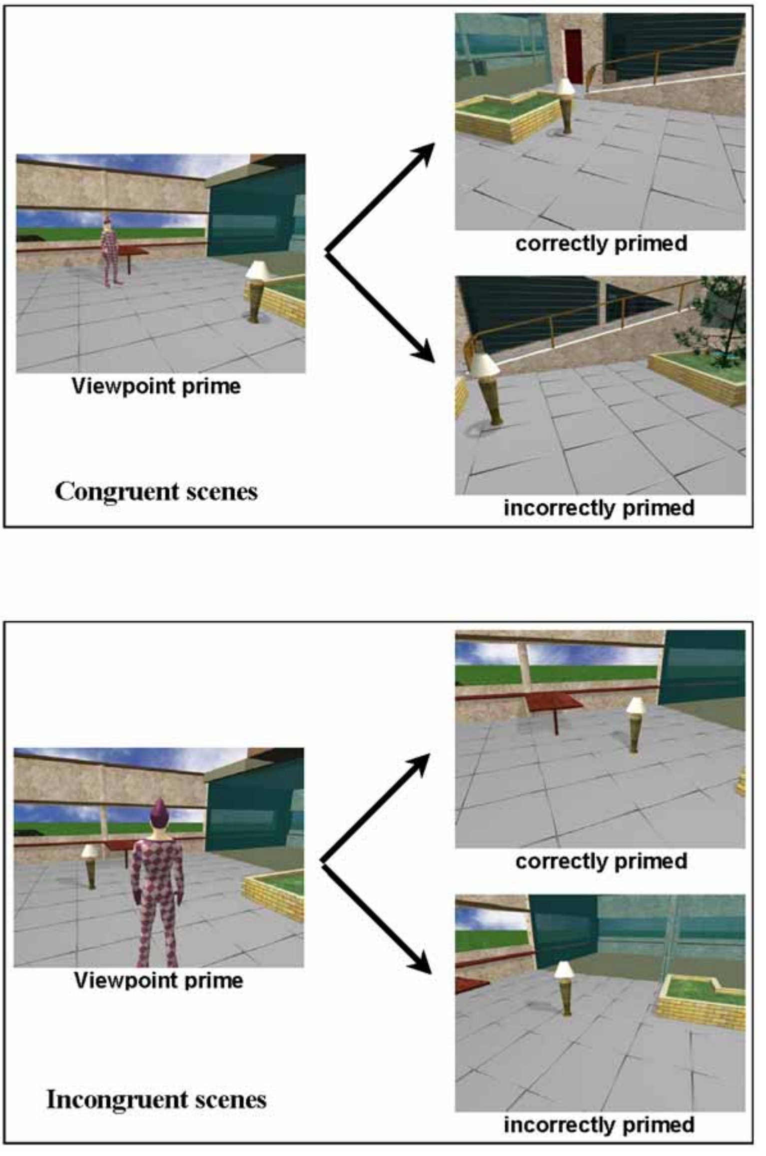


Figure 6. Illustration of the ‘‘self-location’’ condition (Experiments 2 and 3). After examining an initial view for 5 s, observers indicated if the new viewpoint was the one they expected according to the ‘‘out-of-body’’ prime, irrespective of any change in the lamp position. The upper example shows correctly (135° viewpoint change) and incorrectly (180°) primed viewpoints for congruent scenes, i.e., the lamp did not move across viewpoint change. The lower example shows correctly (0° viewpoint change) and incorrectly (45°) primed viewpoints for incongruent scenes, i.e., the lamp changed its position across views. (To view this figure in colour, please see the online issue of the journal.)

then the ‘‘self-location’’ condition, whereas the order was reversed for the other participants.

Results and discussion

‘‘Object location’’ task. Let’s consider first, the effect of ‘‘out-of-body’’ priming on ‘‘object location’’ judgements. On average, priming did not improve performance, neither for RTs ($F < 2.2$) nor for accuracy ($F < 1.9$). However, the effect of angular difference between viewpoints varied significantly with priming (Figure 7) for both RTs, $F(4, 92) = 4.74$, $p < .01$, and accuracy, $F(4, 92) = 4.68$, $p < .01$. A linear trend in performance was observed only in the ‘‘no priming’’ condition, consistent with ‘‘out-of-body’’ priming reducing viewpoint dependence on performance (Table 2 and Figure 7). There was also a nonlinear component in the ‘‘no priming’’ condition for reaction times due to a decrease of RTs for opposite perspective change (180°). This effect is typical of perspective change studies (Easton & Sholl, 1995; Hintzman, O’Dell, & Arndt, 1981; Rieser, 1989) showing that targets either adjacent or opposite to the imagined orientation of the observer are accessed more quickly.

‘‘Self-location’’ task. With respect to the ‘‘self-location’’ condition, on average, congruent scenes across viewpoint change tended to increase response speed, $F(1, 23) = 3.48$, $p < .08$, and more marginally accuracy, $F(1, 23) = 3.09$, $p < .10$. Overall, the angular difference between viewpoints affected self-location judgements both in terms of response time, $F(4, 92) = 5.50$, $p < .001$, and accuracy, $F(4, 92) = 4.34$, $p < .01$. However, the effect of angular difference between viewpoints varied significantly as a function of scene congruence for accuracy, $F(4, 92) = 3.79$, $p < .01$, but not for RTs ($F < 1$). Self-location judgements showed systematically greater viewpoint dependence for incon-

TABLE 2
Trend analysis for each condition of the ‘‘object location’’ task (Experiment 2)

	Reaction time	*% correct*
‘‘Out-of-body’’ priming		
Main effect	$F(4, 92) = 1.61$‡	$F(4, 92) < 1$‡
Linear component	$F(1, 23) < 1$‡	$F(1, 23) < 1$‡
Nonlinear component	$F(3, 69) = 1.96$‡	$F(3, 69) < 1$‡
No priming	(LIN effect = +250 ms)	(LIN effect = −5.5%)
Main effect	$F(4, 92) = 9.47$****	$F(4, 92) = 7.43$****
Linear component	$F(1, 23) = 25.76$****	$F(1, 23) = 17.72$***
Nonlinear component	$F(3, 69) = 3.57$*	$F(3, 69) = 1.25$‡

F tests with * $p < .05$; *** $p < .001$; **** $p < .0001$; ‡ n.s.

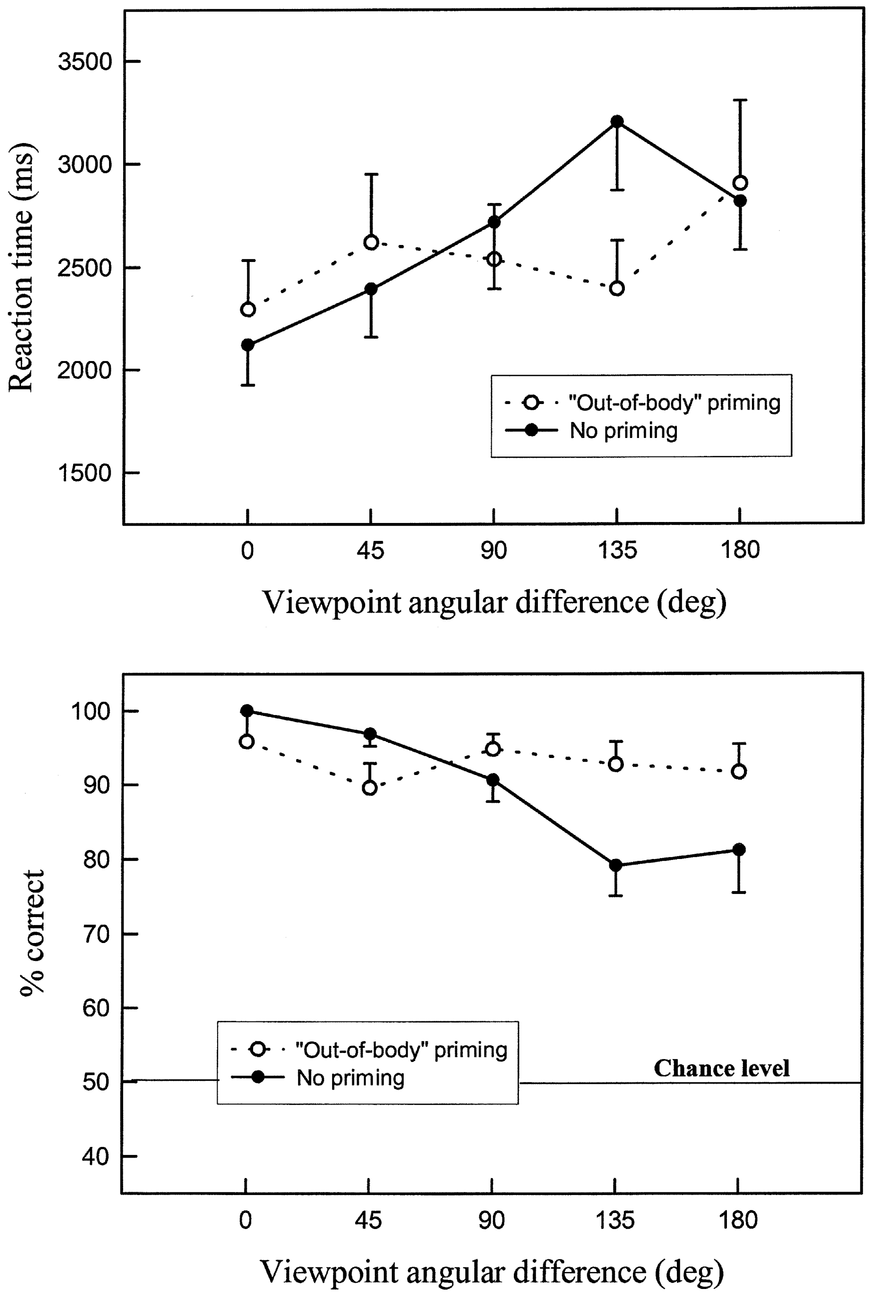


Figure 7. Performance in Experiment 2 at the ''object location'' task as a function of priming and viewpoint angular difference conditions. Error bars indicate standard errors.

gruent scenes as illustrated by highly significant linear trends and an additional 30 ms in linear effect per angular increment (45°) as compared to congruent scenes (Table 3 and Figure 8). These results fit well with Christou et al. (1999) finding that object recognition in a room is facilitated when object-to-environment spatial relations are kept consistent across views so that observer's relative orientation with respect to the objects can be derived from the room.

On average, correct primes increased response speed (mean RT = 2516 ms; $SE = 287$), $F(1, 23) = 7.25$, $p < .05$, and accuracy (mean accuracy = 87.9%; $SE = 5.2$), $F(1, 23) = 12.77$, $p < .01$, as compared to incorrect primes (mean RT = 2704 ms; $SE = 302$ and mean accuracy = 74.6%; $SE = 7.9$). Interestingly, the effect of viewpoint priming tended to vary, $F(4, 92) = 2.36$, $p < .06$, as a function of angular difference between viewpoints for response accuracy (Figure 9).

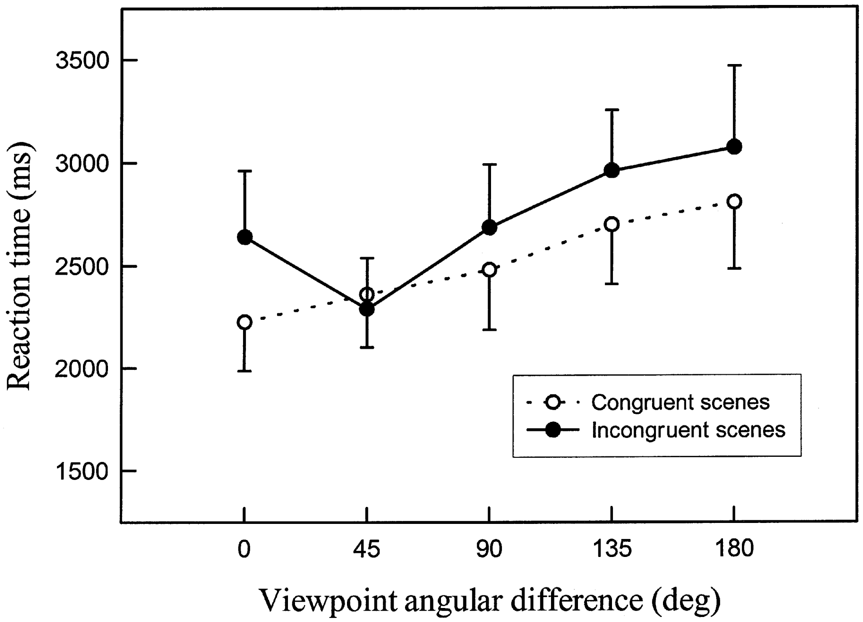
In fact, a trend analysis of this marginally significant interaction shows a significant linear effect of angular difference in viewpoint, $F(1, 23) = 10.80$, $p < .01$, for incorrect primes and no significant nonlinear component ($F < 1$). In contrast, correct primes showed a significant nonlinear effect of viewpoint angular difference, $F(3, 69) = 3.40$, $p < .05$, and no significant linear component ($F < 1.8$). The linear trend on accuracy observed for incorrect viewpoint primes suggests that observers recalled their initial viewpoint for memory to reconstruct the expected viewpoint *again* and compare it to their current (new) viewpoint via mental rotation, in order to reject it as the expected viewpoint. Finally, angular difference and viewpoint priming (correct vs. incorrect primes) did not interact on response time ($F < 1$). No other interaction between factors was observed for response speed and accuracy.

Contrary to Experiment 1, the benefit of ''out-of-body'' priming on overall detection of a change in an ''object location'' after a perspective change was not observed. This difference may be attributed to the fact that in Experiment 2 observers were made familiar with the environment by virtual tours preliminary to

TABLE 3
Trend analysis for each condition of the ''self-location'' task (Experiment 2)

	Reaction time	*% correct*
Congruent scenes	(LIN effect = +153 ms)	
Main effect	$F(4, 92) = 2.01$‡	$F(4, 92) = 2.20$‡
Linear component	$F(1, 23) = 7$*	$F(1, 23) = 1.72$‡
Nonlinear component	$F(3, 69) < 1$‡	$F(3, 69) = 2.41$‡
Incongruent scenes	(LIN effect = +183 ms)	(LIN effect = −6.4%)
Main effect	$F(4, 92) = 4.37$**	$F(4, 92) = 6.18$***
Linear component	$F(1, 23) = 11.85$**	$F(1, 23) = 19.82$***
Nonlinear component	$F(3, 69) = 1.97$‡	$F(3, 69) = 1.18$‡

F tests with * $p < .05$; ** $p < .01$; *** $p < .001$; ‡ n.s.



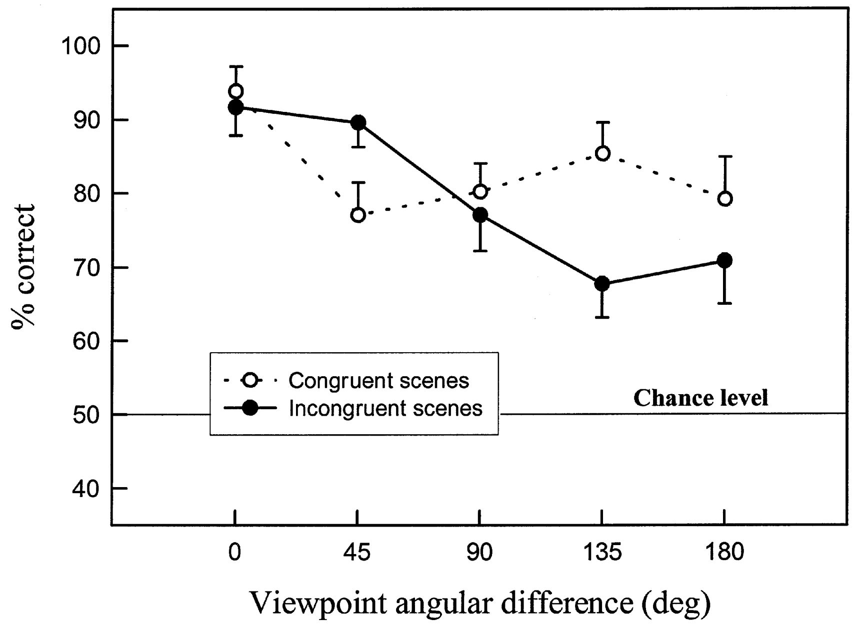


Figure 8. Performance in Experiment 2 at the ''self-location'' task as a function of scene congruence and viewpoint angular difference conditions. Error bars indicate standard errors.

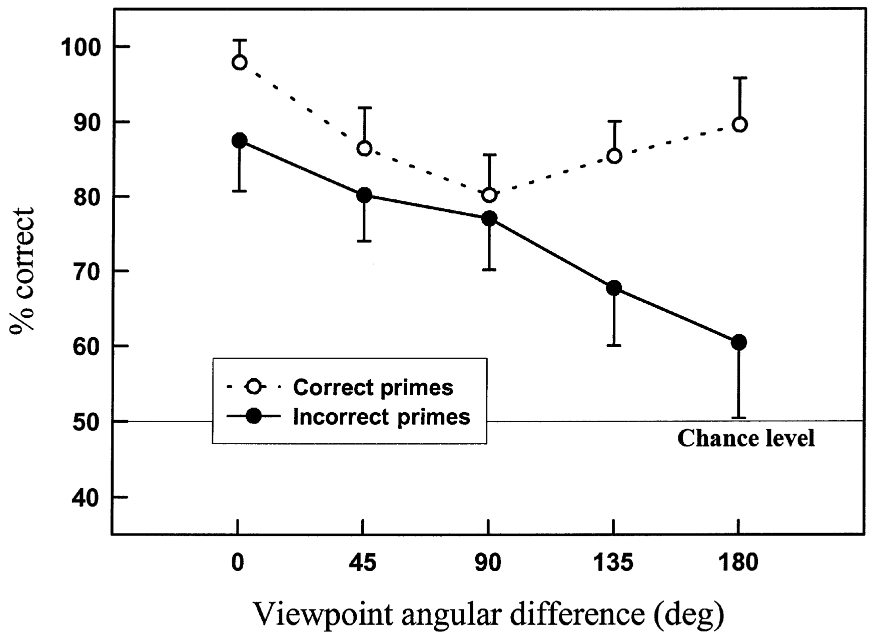


Figure 9. Percentage of correct response in Experiment 2 at the ‘‘self-location’’ task as a function of viewpoint priming (correct vs. incorrect primes) and angular difference conditions. Error bars indicate standard errors.

the experimental tasks. According to the model proposed in Figure 1, these tours provided a spatial knowledge to the observers that acted as a prime for the spatial judgements. Under the assumption that following a perspective change subjects might use mental rotation to match both the new and initial viewpoints, one might expect that in trials where the perspective change corresponds to a clockwise (leftward) perspective change ($-45°$, $-90°$, or $-135°$) observers will rotate the visual scene counterclockwise in order to match it to their initial perspective. In contrast, after counterclockwise (rightward) perspective changes (+45°, +90°, or +135°) observers would perform a clockwise mental rotation. Given that the familiarity tours experienced before the experiment were performed in the clockwise (CW) direction, if the ‘‘tour priming’’ hypothesis is correct, then one might expect faster responses for counterclockwise (CCW) perspective changes. Therefore, a complementary analysis was conducted on response speed at both spatial tasks *restricting* the analysis *to* 45°, 90°, and 135° perspective changes either CW or CCW. A first ANOVA was conducted on both response speed and accuracy for the ‘‘object location’’ task considering the following factors: Direction of the perspective change (CW vs. CCW) $\times$ Priming (‘‘out-of-body’’ priming vs. no priming). The results indicated that response speed was significantly greater, $F(1,23) = 9.93$, $p < .005$, for CCW perspective changes (mean RT = 2505 ms; SE = 155) than for CW trials (mean RT = 2791 ms; SE=144). In contrast to the previous analysis, the ‘‘out-of-body’’ priming condition (mean RT = 2529 ms; SE = 152) increased response speed significantly, $F(1,23) = 5.21$, $p < .05$, as compared to no priming (mean RT = 2767 ms; SE = 151). No interaction between both factors was observed. No effect of these factors was observed on response accuracy. A second ANOVA was conducted on spatial performance at the ‘‘self-location’’ task. The following factors were considered for this analysis: Direction of the perspective change (CW vs. CCW), priming (correct vs. incorrect viewpoint primes), and scene congruence (congruent or incongruent scenes). The results again revealed that response speed was significantly, $F(1,23) = 5.73$, $p < .03$, increased in CCW trials (mean RT = 2478 ms; SE = 141) as compared to CW perspective changes (mean RT = 2713 ms; SE = 168). Similarly, correctly primed viewpoint induced significantly, $F(1,23) = 8.27$, $p < .01$, faster responses (mean RT = 2423 ms; SE = 160) than following incorrect primes (mean RT = 2768 ms; SE = 157). None of the three factors interacted on response speed. Neither these factors affected response accuracy. In summary, the results of these two ANOVAs are consistent with the previously mentioned hypothesis, namely that the initial tour in the environment experienced by the participants before the experiment allowed them to developed a dynamic spatial knowledge that facilitated subsequent spatial judgements that required mental rotation compatible with the CW direction of the initial tour.

A more complete manipulation of angular disparities between viewpoints, as compared to Experiment 1, allowed to conduct trend analyses to study the modulation of viewpoint dependence by ‘‘out-of-body’’ priming. Results showed that ‘‘out-of-body’’ priming suppressed viewpoint dependence in the ‘‘object location’’ task. When the task was to determine if the new viewpoint was the one expected according to the prime (‘‘self-location’’ task), linear viewpoint dependence of response accuracy was observed for incorrect viewpoint primes. A nonlinear U-shaped trend was observed for correct primes, with more errors observed for viewpoint changes orthogonal to the initial perspective on the visual scene. Interestingly, the results showed that when viewpoint change increases, observers tend to answer randomly for incorrectly primed viewpoints; on the opposite, their judgements are greatly improved following correct primes. Therefore, there is a substantial benefit of ‘‘out-of-body’’ priming for anticipating the visual consequences of a perspective change. Results from literature on posture recognition suggest that having seen the same action or pose facilitates its future identification provided that the priming and primed actions share the same in-depth orientation (Daems & Verfaillie, 1999; Olofsson, Nyberg, & Nilsson, 1997). Similarly, the results of Experiment 2 show that the postural information provided in the ‘‘out-of-body’’ perspective facilitates viewpoint change judgements when the priming posture and the primed viewpoint share the same in-depth orientation.

Experiment 2 has shown that introducing an incongruence in object-to-object or object-to-environment spatial relations across viewpoint change is detrimental to ''out-of-body'' priming. This finding raises the issue of the interplay of the multiple reference frames available for anticipating viewpoint change on the basis of ''out-of-body'' priming. In an architectural environment such as the one used in Experiment 1 and 2, spatial judgements can be made on the basis of multiple frames of reference: Object-to-object, self-to-object, object-to-environment, self-to-environment. In order to study the relative contribution of the object-to-object and environmental frames of reference to ''out-of-body'' priming of perspective change, Experiment 3 compared spatial performance in two different environments. The previous architectural environment provided a condition where object-to-object and environment frames of reference were available, whereas an array of furniture in an open-field provided an object-to-object frame of reference alone.

EXPERIMENT 3

Previous perspective change studies in real environments were performed relative to target objects positioned either inside a well-structured functionally organized environment such as a classroom, a library, or a kitchen (Presson & Montello, 1994; Rieser, Garing, & Young, 1994; Young, 1989) or in a poorly structured experimental room (Creem, Wraga, & Proffitt, 2001b; Easton & Sholl, 1995; Huttenlocher & Presson, 1979; May, 1996; Rieser, 1989; Shelton & McNamara, 1997; Wraga et al., 2000). Scene recognition or perspective change studies in virtual environments are usually performed inside architectural or highly structured environments (Amorim & Stucchi, 1997; Amorim et al., 2000; Christou & Bülthoff, 1999). However, the relative importance of environmental and object-centred frames references for scene recognition across views was not directly investigated. Recent studies on spatial orientation provide evidence that movable objects (even large ones) are encoded differently from nonmovable extended surfaces such as walls (Gouteux & Spelke, 2001; Wang & Spelke, 2000). As an example, Gouteux and Spelke compared adults' and 3- to 4-year-old children's ability to reorient themselves and locate a hidden object after being disoriented in a room containing a geometric configuration of movable landmarks. These authors showed that, in contrast to adults, children selectively reorient by detecting the geometrical arrangement of the extended surfaces in their environment (i.e., its walls) but not the geometric arrangement of the movable objects in this environment.

Experiment 3 examined how the coordination of out-of-body and embodied perspectives for scene recognition across views is modulated by the presence or absence of an environmental frame of reference. Additionally, in order to test the hypothesis that the overall benefit of ''out-of-body'' priming on detection of a change in ''object location'' across views disappeared in

Experiment 2 because of the familiarity with the environment provided by the initial tour, observers in Experiment 3 were kept unfamiliar with the environment.

Method

Participants. Twenty new individuals aged between 21 and 49 participated in this experiment.

Stimuli and apparatus. A new virtual model as well as picture stimuli were generated using 3DStudio MAX® and Character Studio® as in the previous experiments, everything being equal but the 3D model. This new environment was a square-shaped spatial configuration of furniture under proportions similar to the architectural environment used previously (Figures 3 and 10) but located in an open field. All the participants were unfamiliar with both the architectural and furniture layouts.

Figure 10. Survey perspective on the furniture world used in Experiment 3. The same harlequin location as well as camera and target positions as in Figure 3 are illustrated, to facilitate the comparison of both spatial layouts. (To view this figure in colour, please see the online issue of the journal.)

Procedure and design. The same procedure as in Experiment 2 was applied, with the only difference that observers performed no tour in the environments before the experiment. Examples of experimental trials for both the architectural and furniture spaces are displayed in Figure 11 and 12.

The experimental design was the same as in Experiment 2, with a new within-subjects factor added for both tasks: The spatial layout (architectural vs. furniture world).

Results and discussion

''Object location'' task. Spatial judgements in the architectural spatial layout were performed significantly faster, $F(1, 19) = 21.39$, $p < .001$, and more accurately, $F(1, 19) = 59.88$, $p < .0001$, than in the furniture spatial layout.

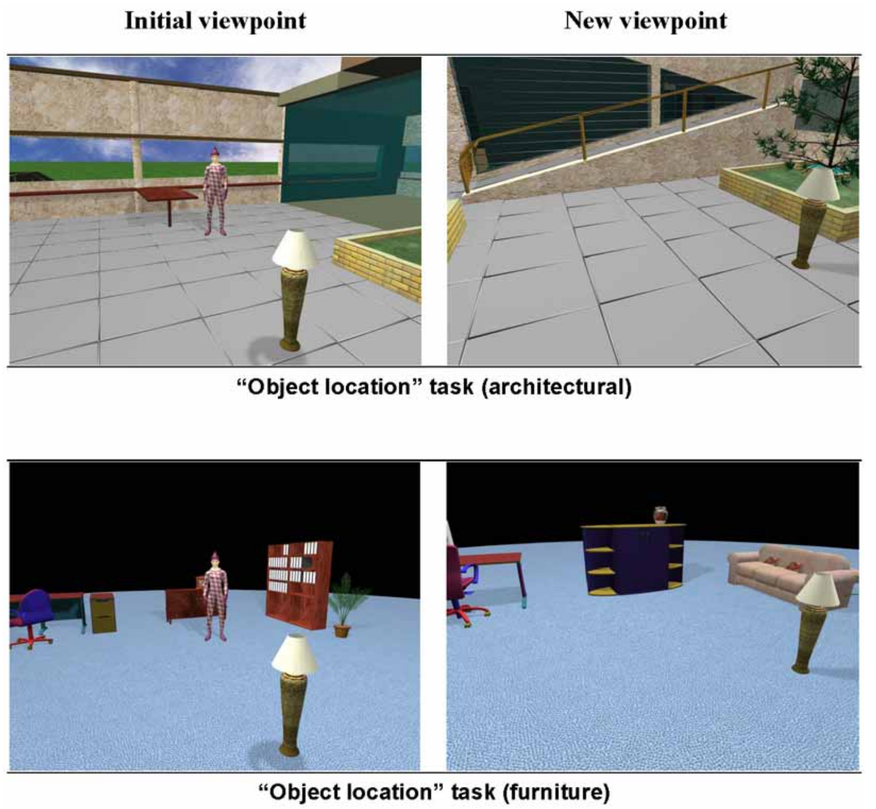


Figure 11. Equivalent ''object location'' trials in the architectural vs. furniture spatial layouts. Out-of-body priming of a 180° viewpoint change, in both cases the lamp has moved across views. (To view this figure in colour, please see the online issue of the journal.)

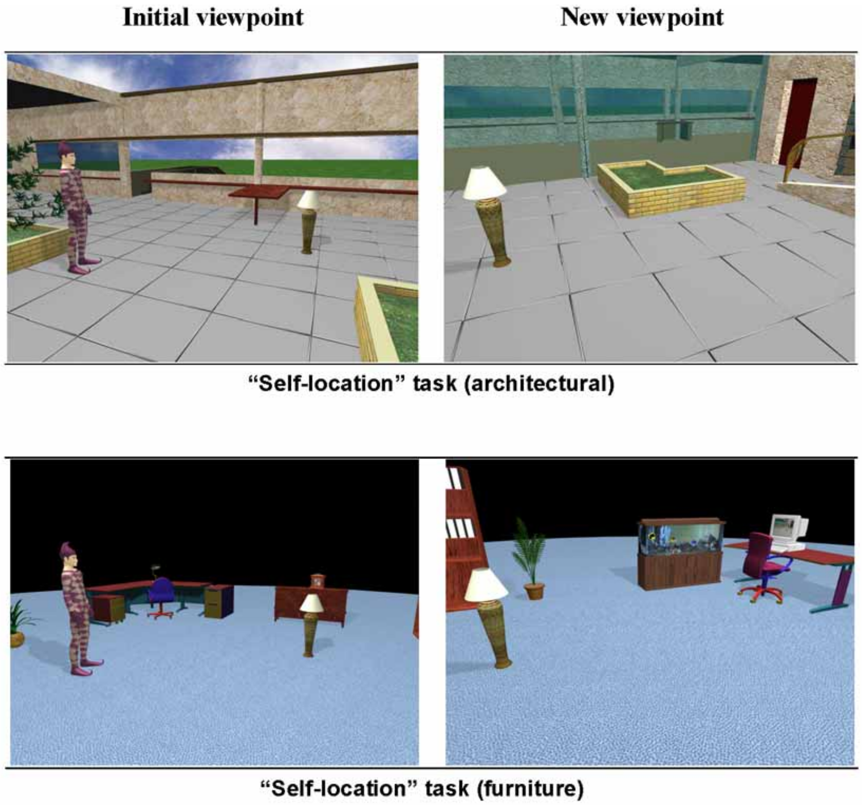


Figure 12. Equivalent ''self-location'' trials in the architectural vs. furniture layouts. Incorrect viewpoint priming in a congruent scene (the lamp did not move across views): A 90° viewpoint change prime is followed by a 135° viewpoint change. (To view this figure in colour, please see the online issue of the journal.)

Detailed mean values as a function of each priming condition are presented in Table 4. Regarding reaction times, the ANOVA showed no global effect of priming, ($F < 1.6$). However although the interaction between spatial layout and priming did not reach significance ($F < 1.6$) a planned comparison was used to test if the predicted overall effect of priming, initially observed in Experiment 1, would come back due similar unfamiliarity of the observers with the environment in both Experiment 1 and 3. The comparison showed an effect of priming for architectural environment, $F(1, 19) = 10.70$, $p < .01$, but not for furniture world ($F < 1$). Considering now response accuracy, performance improved significantly, $F(1, 19) = 7.23$, $p < .05$, with ''out-of-body'' priming. In addition, there was a significant interaction between priming and spatial layout, $F(1, 19) = 13.61$, $p < .01$. These mean results, presented in Table 4, can be summarized as

TABLE 4
Mean (±*SE*) effect of priming for each environment in the ''object location'' task (Experiment 3)

	Reaction time (ms)		*% correct*	
	''Out-of-body'' priming	*No priming*	*''Out-of-body'' priming*	*No priming*
Architecture	2467 (216)	2681 (254)	87.00 (4.22)	85.75 (4.83)
Furniture	3079 (254)	3060 (234)	77.92 (5.88)	66.83 (6.38)
	2773 (246)	2870 (248)	82.46 (5.22)	76.29 (6.04)

follows: In the architectural environment, ''out-of-body'' priming increases response speed and accuracy. In contrast, in the lack of an environmental frame of reference (provided by permanent structures such as walls) like in the furniture spatial layout, the overall spatial performance decreases. So, in order to benefit from priming to improve accuracy, subjects need to keep processing times high.

The results show an overall decrease in response speed, $F(4, 76) = 27.19$, $p < .0001$, and accuracy, $F(4, 76) = 20.23$, $p < .0001$, with the increase in angular disparity between viewpoints. With respect to reaction time, this effect of viewpoint angular difference followed a linear trend, $F(1, 19) = 63.66$, $p < .0001$, without any non-linear component ($F < 1.7$). This linear effect was always present whatever the priming and spatial layout conditions. However, the effect of angular difference in viewpoint interacted with priming and spatial layout for reaction time, $F(4, 76) = 2.89$, $p < .05$, as illustrated in Figure 13. This last result translates the fact that the difference in linear effect between priming conditions was more important in the architectural environment than in the furniture space.

Regarding response accuracy, the effect of angular difference in viewpoint interacted with spatial layout only, $F(4, 76) = 6.00$, $p < .001$. Figure 14 illustrates the fact that for the architectural environment the amplitude of the linear trend was less important, $F(1, 19) = 14.32$, $p < .01$ (mean = -3% per 45°) than the linear trend of the furniture world, $F(1, 19) = 35.18$, $p < .0001$ (mean = -9% per 45°). In addition, the furniture world induced a significant nonlinear component, $F(3, 57) = 6.58$, $p < .001$, in viewpoint dependence, contrary to the architectural environment ($F < 2.4$).

In contrast to Experiment 2, viewpoint dependence of reaction times was observed for the architectural environment in the ''out-of-body'' priming condition of the ''object location'' task. However is should be noted that the amplitude of this linear effect (169 ms per 45°) is two times smaller than in the condition without priming (332 ms per 45°). The fact that the priming condition

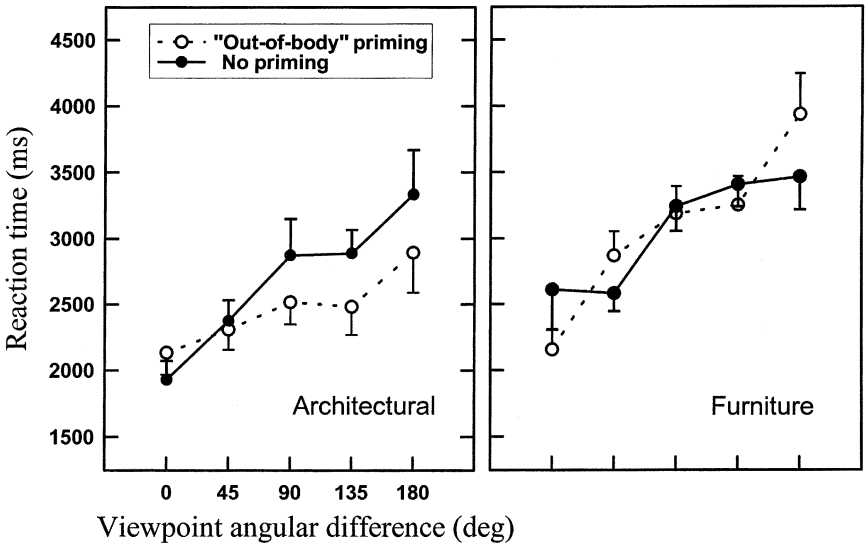


Figure 13. Reaction times in Experiment 3 for the ''object location'' task as a function of priming and viewpoint angular difference conditions for each spatial layout. Error bars indicate standard errors. (The scale is the same for both panels.)

shows viewpoint dependence could be attributed to the unfamiliarity of the observers with the environment, since in Experiment 3 no initial tour in the virtual environment was performed. This initial tour in Experiment 2, provided participants with a spatial knowledge that facilitated self orientation and scene recognition across views. Apropos the effect of the spatial layout on spatial judgements, viewpoint dependence of response accuracy was greater in the furniture world than inside the architectural environment (Figure 14). Performance reaches chance level for 135° and 180° perspective changes in the furniture layout. The absence of an environmental permanent layout definitely impairs spatial orientation. This results fits well with other studies (Wang & Spelke, 2000) showing that adults who are disoriented maintain accurate representations of the surface layout (e.g., an arrangement of room corners) but not of separated objects (e.g., a geometrically identical arrangement of chairs). The presence of an extended permanent surface layout providing an environmental reference frame facilitates spatial orientation and scene recognition across views. Similarly, Rieser, Frymire, and Berry (1997) provided evidence that imagining a permanent environment facilitates spatial updating when walking without vision. Their subjects were guided without vision along a four-segment route at the end of which they were asked to return to the starting position alone (homing task). In one condition called ''virtual ganzfeld'' subjects were initially disoriented by a 10 min blindfolded circuitous walk around

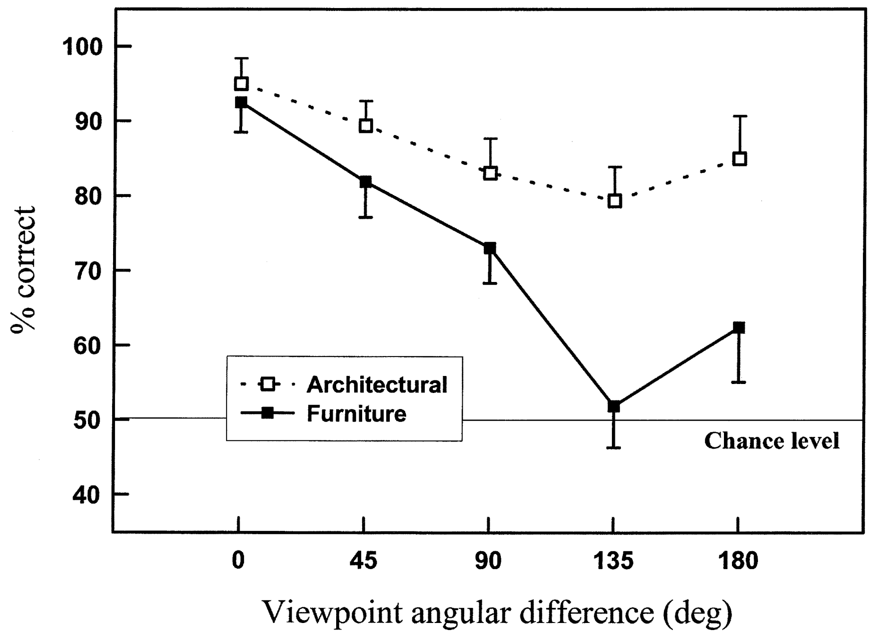


Figure 14. Percentage of correct response in Experiment 3 at the ''object location'' task as a function of viewpoint angular difference for each spatial layout. Error bars indicate standard errors.

campus, then they performed the homing task. Actually, subjects mentioned imagining themselves to be in a large, featureless empty field, while travelling along the test paths. In the ''actual surroundings'' condition, before each trial, subjects viewed their actual surroundings and updated the location of several landmarks while walking without vision. Finally, in a third ''imagined surroundings'' condition, after being initially disoriented as in the ''virtual ganzfeld'' condition, they were asked to generate a mental image of the surroundings of a known environment, and then to keep in mind several landmarks of the imagined place while walking the test paths. The results indicate that subjects performed the homing task more accurately in the actual surroundings condition than in the virtual ganzfeld condition. In addition, the imagined surroundings provided intermediate performance, however, significantly better than in the virtual ganzfeld condition. Even though a mental image of the environment provides no information about current position and orientation, these results suggest that its presence in memory seems to facilitate spatial updating when walking without vision.

''Self-location'' task. ''Self-location'' judgements were performed more accurately in the architectural environment, $F(1, 19) = 13$, $p < .01$ (mean

accuracy = 78.3%, *SE* = 7.8), than in the furniture space (mean accuracy = 71%, *SE* = 8.8), and marginally more rapidly, $F(1, 19) = 3.36$, $p < .09$ (architectural environment mean RT = 2777 ms, *SE* = 311, and furniture world mean RT = 2905 ms, *SE* = 325). With respect to the effect of priming on ''self location'', correct primes increased both response speed, $F(1, 19) = 18.37$, $p < .001$, (mean RT = 2667 ms, *SE* = 311) and accuracy, $F(1, 19) = 15.28$, $p < .001$, (mean accuracy = 81.8%, *SE* = 7.3) as compared to incorrect primes (mean RT = 3015 ms, *SE* = 320 and mean accuracy = 67.5%, *SE* = 9).

Although scene congruence affected neither response speed ($F < 1$) nor accuracy ($F < 1$), it interacted with spatial layout for accuracy, $F(1, 19) = 13.12$, $p < .01$, but not for response times ($F < 1$). Post hoc Scheffé tests on this interaction (Figure 15 left panel) revealed that congruent scenes led to more accurate responses ($p < 0.01$) for the architectural rather than the furniture spatial layout. Moreover, incongruent scenes degraded accuracy marginally ($p < .08$) for the architectural environment, whereas it did not change performance for the other spatial layout ($p > .13$).

Viewpoint priming interacted with spatial layout on accuracy, $F(1, 19) = 5.69$, $p < .05$, but not for response times ($F < 2.5$). Post hoc Scheffé tests on this interaction (Figure 15 right panel) indicated that correct primes increased performance as compared to incorrect primes, inside the architectural environment

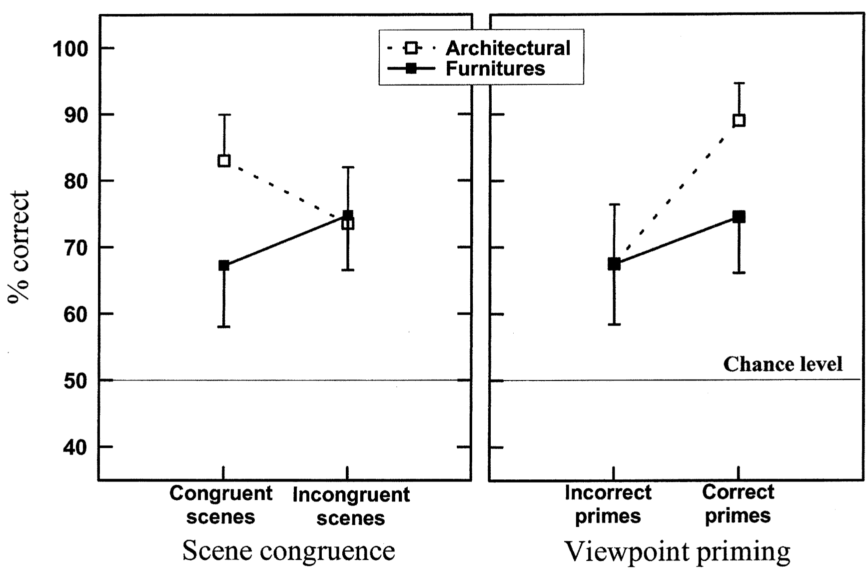


Figure 15. Percentage of correct response in Experiment 3 at the ''self-location'' task as a function of scene congruence or viewpoint priming conditions for each spatial layout. Error bars indicate standard errors.

($p < .001$) but not for the furniture world ($p > .46$); and that judgements performed in the architectural environment benefited more from correct primes ($p < .05$) than in the furniture world.

The ANOVA showed a significant Priming × Scene congruence × Spatial layout interaction for response accuracy, $F(1, 19) = 11.43$, $p < .01$. Post hoc Scheffé tests were performed in order to better understand this complex interaction. Results indicated that, when preceded by incorrect primes, congruent scenes in the furniture spatial layout or incongruent scenes in the architectural environment lead to less accurate spatial judgements than for congruent or incongruent scenes in the architectural environment that were preceded by correct primes ($p < .01$ for each of these paired comparisons). No other paired comparison was significant (always $p > .10$). Neither scene congruence nor priming interacted with other experimental factors on RTs.

Finally, performance was affected by angular difference in viewpoint, showing linear trends suggestive of viewpoint dependence (Table 5). However, angular difference in viewpoint never interacted with the other experimental factors neither for RTs nor response accuracy.

Experiment 2 revealed that introducing an incongruence in object-to-object or object-to-environment spatial relations across viewpoint change is detrimental to ''out-of-body'' priming. This effect was replicated in Experiment 3, however, in contrast to the previous experiment, the effect of scene congruence varied as a function of viewpoint priming: Incorrect primes had a more deleterious effect on spatial judgements when scene congruence was not preserved across views. The fact that judgements performed in the architectural environment benefited more from scene congruence and viewpoint priming is another interesting finding that pinpoints the importance for spatial orientation of an environmental permanent layout provided by nonmovable extended structures. In addition, the absence of

TABLE 5
Mean (±*SE*) effect of viewpoint angular difference on performance and trend analysis of the ''self-location'' task (Experiment 3)

	Reaction time	*% correct*
0°	2486 (340)	90.63 (6.52)
45°	2601 (273)	80.31 (6.74)
90°	3002 (281)	67.81 (7.84)
135°	2966 (279)	66.88 (8.19)
180°	3152 (377)	67.50 (10.47)
	(LIN effect = +170 ms)	(LIN effect = −6%)
Main effect	$F(4, 76) = 7.77$****	$F(4, 76) = 15.67$****
Linear component	$F(1, 19) = 40.07$****	$F(1, 19) = 70.31$****
Nonlinear component	$F(3, 57) < 1$‡	$F(3, 57) = 3.82$*

F tests with *$p < .05$; ****$p < .0001$; ‡ n.s.

an initial spatial knowledge provided by an initial tour such as in Experiment 2 might have contributed to the modulation of viewpoint priming by scene congruence observed in Experiment 3. According to the model of Figure 1, the results suggest that when observers cannot match the new viewpoint to a spatial knowledge, such as the one provided by the initial tours in Experiment 2, then spatial judgements are more sensitive the interplay of scene congruence and viewpoint priming. Similarly, mental rotation following viewpoint change perspective will not be facilitated as revealed by the absence of a difference between CCW and CW perspective changes in Experiment 3, for both spatial tasks.

GENERAL DISCUSSION

Although switching perspective in order to take another person's point of view such as a doll visible from the initial viewpoint, is a common task for the study of children's spatial ability (see the introduction), this kind of paradigm was never used with adults. Instead, studies with adults have involved localizing objects after imaginary self rotation outside (Creem et al., 2001b; Huttenlocher & Presson, 1979; Juurmaa & Lehtinen-Railo, 1994; May, 1996; Shelton & McNamara, 1997; Wraga et al., 1999) or inside (Easton & Sholl, 1995; Presson & Montello, 1994; Rieser, 1989; Young, 1989) a stable array of objects. Self rotation inside an array of objects involves only a change in direction, whereas self rotation around an array of objects involves a change in both self-to-object orientation and distance. Imagined self-translations alone were also studied (Presson & Montello, 1994; Rieser, 1989). Only recently (Amorim et al., 2000; Juurmaa & Lehtinen-Railo, 1994) has the ''out-of-body'' or ''doppelganger'' strategy been examined to imagine a new viewpoint from a given view. Paradoxically, switches of viewpoints between ''observer'' (''out-of-body'') and ''field'' (''embodied'') perspectives (Lorenz & Neisser, 1985; Robinson & Swanson, 1993) are popularly illustrated in 3D computer games or cinematography where observers are involved in a permanent process of scene recognition across views.

Research on scene recognition across views has provided evidence that interobject spatial relations are mentally represented in a viewpoint-dependent manner (Diwadkar & McNamara, 1997; Shelton & McNamara, 1997; Simons & Wang, 1998; Wang & Simons, 1999), as illustrated by the linear dependence of both recognition latency and response accuracy on the angular distance between test and study views (Diwadkar & McNamara, 1997; Shelton & McNamara, 1997). Here, three experiments examined the ability of observers either to detect a change in an object location inside a virtual environment (''object location'' condition) or a change in expected self location after a ''doppelganger'' or ''out-of-body'' priming of the perspective change (''self-location'' condition). The results indicated that ''out-of-body'' priming modulates viewpoint dependence of perspective change.

Let's consider first the ''object location'' task requiring observers to detect a change in location of an outstanding object after a viewpoint change. If observers are made familiar with the virtual environment (Experiment 2) viewpoint priming abolishes viewpoint dependence. However, if observers are unfamiliar with the environment (Experiment 3) viewpoint dependence is observed even in the priming condition although to a much lesser extent than when observers cannot anticipate what their new viewpoint on the visual scene will be. Under conditions of nonfamiliarity with the environment, viewpoint dependence of perspective change is always present. Besides viewpoint dependence, one might consider the overall effect of priming on performance. Results indicate that in environments unfamiliar to the observers (Experiments 1 and 3) ''out-of-body'' priming improved spatial judgements on object location.

When the spatial judgements require from the observer to judge if the new viewpoint is the one expected according to the ''out-of-body'' prime, viewpoint dependence is observed for incorrect primes. Moreover, viewpoint priming for judging ''self-location'' improves performance when the spatial layout involves an environmental frame of reference, such as in the architectural environment. Introducing an incongruence in object-to-object or object-to-environment spatial relations across viewpoint change is detrimental to ''out-of-body'' priming, and increases viewpoint dependence when the environment is familiar to the observer (Experiment 2). When the environment is new to the observer, judging ''self location'' after viewpoint change is subject to viewpoint dependence. However, scene congruence across viewpoints improves judgements for an architectural layout rather than inside an array of objects. The detrimental effect of scene incongruence is increased when judgements are preceded by incorrect viewpoint primes; again, viewpoint priming modulates spatial judgements. The deleterious effect of incongruent spatial information across perspective change (due to the change in position of an outstanding object that observers were asked to ignore) is compatible with Christou et al. (1999) finding that keeping object-to-environment spatial relations consistent across views facilitates self-location judgements and subsequent object recognition in a room.

A visuospatial model of "out-of-body" priming

In terms of neurocognitive modelling, the findings of the present study make sense in the light of the hypothetical processes, presented in the introduction and illustrated in Figure 1, that would be involved in the coordination of out-of-body and embodied perspectives. Spatiotopic mapping allows observer to take advantage of the postural information provided by their virtual avatar (out-of-body perspective) that specifies their future embodied perspective on the visual scene. Both coordinate and categorical encoding of the spatial relations between the avatar and the available frames of reference (object-to-object and environment) provided by spatial landmarks can be established from scanning the visual scene, e.g., the lamp would be 45° (coordinate) on my left side (categorical). The more permanent and extended are the spatial landmarks (e.g., walls and hallways), the more easily the future viewing direction can be extrapolated from the virtual avatar head direction (STS and intraparietal sulcus), as indicated by the higher spatial performance in the architectural environment as compared to the furniture spatial layout. Once the future viewing direction is detected a ''shift'' process may be used to transform (mental rotation) the visual scene in order to anticipate more precisely the visual content of the future perspective. If a spatial knowledge is available, such as from a previous tour in the environment (Experiment 2), an already memorized view onto the environment can be instantiated, supposedly via reactivation of hippocampal spatial views cells. This ''blink'' process (Kosslyn, 1980, 1987) or regenerative strategy (Huttenlocher & Presson, 1973) would be as efficient as mental transformation of the visual scene on the basis of ''shift'' processes (mental scanning and/or mental rotation).

Consequently, if from the initial viewpoint there is not enough time available to anticipate the future perspective on the visual scene, or if there is no advance information on the future vantage position and orientation, the observer will need to match both the initial and current viewpoint, from the new perspective, via a process analogous to mental rotation (Shepard & Metzler, 1971), thereby inducing viewpoint dependence of perspective change. Therefore, viewpoint dependence of scene recognition across views can be regarded as a post-processing by-product. Similarly, the fact that viewpoint dependence was observed for the architectural environment when it was unfamiliar to the observer (Experiment 3), in spite of being primed on the future perspective, might be attributed to the fact that it takes more time to generate a mental image of the future viewpoint from ''scratch'' than from available spatial knowledge (that is, when the environment is already familiar to the observer). In this case, the 5 s of observation from the initial viewpoint were not enough to generate the future perspective mentally. This fits well with Cooper and Shepard's (1973) finding that mental rotation, whether pre- or poststimulus (the stimulus is here the new viewpoint), can be performed under the provision of a minimal processing time cost. If for any reason the advance information is not reliable (incorrect viewpoint prime or incongruent spatial information across views) additional mental transformations (postprocessing) are engaged that will induce viewpoint dependence of spatial performance, especially in the absence of a clear environmental frame of reference.

Spontaneous ''out-of-body'' imagery as a cognitive style?

The anticipation of future viewpoint on the basis of an avatar closely resembles the paradigms used with children to study perspective change (Piaget & Inhelder, 1956). The pioneering tasks required to imagine or to represent how objects look relative to one another from this visually available avatar, whether a doll (Fishbein et al., 1972) or an animal (Huttenlocher & Presson, 1973). One may wonder whether video games, where switching between ''out-of-body'' and ''embodied'' perspectives is common, might or might not improve children's spatial ability for perspective change. The work of Judy Sachter (1990, 1991) gives us some clues regarding this question. Her study focused on the children's use of different representations and strategies when constructing, transforming, and displacing objects in a 3D computer world called ''J3D'' made of geometric primitives such as Biederman's (1987) geons (cone, cube, sphere, or cylinder). She asked children at the frontier of the Piagetian operational stage of development (about 9 years old), to explain what caused the difference between two presented views of the same spatial layout. Their initial interpretation varied from ''a rotation of the visual scene'', to ''a change in viewpoint'', or ''a change in object's position'', from trial to trial. However, after becoming familiar with J3D virtual world, they chose only one spatial transformation, whatever it was, that reflected their cognitive style related to spatial cognition. This finding suggests that children favouring perspective change interpretation to account for spatial transformation would benefit more from video games with alternating ''out-of-body'' and ''embodied'' perspectives.

Finally, although the present study is definitely not a contribution to the comprehension of spontaneous OBE, in contrast, the study of the spatial skills of individuals who have OBEs (Cook & Irwin, 1983) may add to the understanding of perspective change ability. As an example, a recent survey among 52 children aged between 5 and 12 (Blackmore & Woofitt, 1990) reported only one OBE case in an 11-year-old child during an intense stress episode when he was 9. Interestingly, it is only about 9–10 years of age that children can indicate how a spatial configuration looks like to another observer (Morrs, 1987). This again illustrates well, from a developmental approach, how much the coordination of out-of-body and embodied perspectives may be closely related to the necessary maturation of the neurocognitive substrate underlying perspective-taking ability in order to modulate viewpoint dependence of scene recognition across views.

REFERENCES

Aguirre, G. K., & D'Esposito, M. (1997). Environmental knowledge is subserved by separable dorsal/ventral neural areas. *Journal of Neuroscience, 17*, 2512–2518.

Aguirre, G. K., Detre, J. A., Alsop, D. C., & D'Esposito, M. (1996). The parahippocampus subserves topographical learning in man. *Cerebral Cortex*, *6*, 823–829.

Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: Role of the STS region. *Trends in Cognitive Sciences*, *7*, 267–278.

Alvarado, C. S. (1992). The psychological approach to out-of-body experiences: A review of early and modern developments. *Journal of Psychology*, *126*, 237–250.

Amorim, M.-A., & Stucchi, N. (1997). Viewer- and object-centered mental explorations of an imagined environment are not equivalent. *Cognitive Brain Research*, *5*, 229–239.

Amorim, M.-A., Trumbore, B., & Chogyen, P. L. (2000). Cognitive repositioning inside a desktop VE. *Presence: Teleoperators and Virtual Environments*, *9*, 165–186.

Andersen, R. A., Snyder, L. H., Bradley, D. C., & Xing, J. (1997). Multimodal representation of space in the posterior parietal cortex and its use in planning movements. *Annual Review of Neuroscience*, *20*, 303–330.

Beringer, J. (1994a). CiP94 abstracts: ERTS-IPL: Tachistoscopic color image displays and accurate response registration on IBM PCs. *Psychology Software News*, *5*, 37–38, CTI Centre for Psychology, University of York, UK.

Beringer, J. (1994b). Software announcements—ERTS: A flexible software tool for developing and running psychological reaction time experiments on IBM PCs. *Behavior Research Methods, Instruments, and Computers*, *55*, 1.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*, 115–147.

Blackmore, S. (1987). Where am I?: Perspectives in imagery and the out-of-body experience. *Journal of Mental Imagery*, *11*, 53–66.

Blackmore, S. J., & Woofitt, R. C. (1990). Out-of-body experiences in young children. *Journal of the Society for Psychical Research*, *56*, 155–158.

Burgess, N., Maguire, E. A., Spiers, H. J, & O'Keefe, J. (2001). A temporoparietal and prefrontal network for retrieving the spatial context of lifelike events. *NeuroImage*, *14*, 439–453.

Carlson-Radvansky, L. A., & Irwin, D. E. (1993). Frames of references in vision and language: Where is above? *Cognition*, *46*, 223–244.

Christou, C. G., Bosco, S. T., & Bülthoff, H. H. (1999). *Viewpoint information provided by a familiar environment facilitates object identification* (Tech. Rep. N0. 68). Tübingen, Germany: Max-Planck-Institute for Biological Cybernetics.

Christou, C. G., & Bülthoff, H. H. (1999). View dependence in scene recognition after active learning. *Memory and Cognition*, *27*, 996–1007.

Coles, M. E., Turk, C. L., Heimberg, R. G., & Fresco, D. M. (2001). Effects of varying levels of anxiety within social situations: Relationship to memory perspective and attributions in social phobia. *Behaviour Research and Therapy*, *39*, 651–665.

Cook, A. M., & Irwin, H. J. (1983). Visuospatial skills and the out-of-body experience. *Journal of Parapsychology*, *47*, 23–35.

Cooper, L. A., & Shepard, R. N. (1973). Chronometric studies of the rotation of mental images. In W. G. Chase (Ed.), *Visual information processing* (pp. 75–176). New York: Academic Press.

Cox, M. V. (1977). Perspective ability: The relative difficulty of the other observer's viewpoint. *Journal of Experimental Child Psychology*, *24*, 254–259.

Creem, S. H., Downs, T. H., Wraga, M., Harrington, G. S., Proffitt, D. R. , & Downs, J. H. III (2001a). Neural mechanisms involved in imagined self-rotation: An fMRI study. *Cognitive, Affective, and Behavioral Neuroscience*, *1*, 239–249.

Creem, S. H., Wraga, M., & Proffitt, D. R. (2001b). Imagining physically impossible self-rotations: Geometry is more important than gravity. *Cognition*, *81*, 41–64.

Crovitz, H. F. (1971). The capacity of memory loci in artificial memory. *Psychonomic Science*, *24*, 187–188.

Cutting, J. E. (1997). How the eye measures reality and virtual reality. *Behavior Research Methods, Instruments, and Computers*, *29*, 27–36.

Daems, A., & Verfaillie, K. (1999). Viewpoint-dependent priming effects in the perception of human actions and body postures. *Visual Cognition*, *6*, 665–693.

de Araujo, I. E., Rolls, E. T., & Stringer, S. M. (2001). A view model which accounts for the spatial fields of hippocampal primate spatial view cells and rat place cells. *Hippocampus*, *11*, 699–706.

Diwadkar, V. A., & McNamara, T. P. (1997). Viewpoint dependence in scene recognition. *Psychological Science*, *8*, 302–307.

Downs, R., & Stea, D. (1973). *Image and environment: Cognitive mapping and spatial behavior.* Chicago: Aldine.

Easton, R. D., & Sholl, M. J. (1995). Object-array structure, frames of reference, and retrieval of spatial knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 483–500.

Ehrenwald, J. (1974). Out-of-body experiences and the denial of death. *Journal of Nervous and Mental Disease*, *59*, 227–233.

Farrell, M. J., & Robertson, I. H. (1998). Mental rotation and the automatic updating of body-centered spatial relationships. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 227–233.

Finke, R. A., & Pinker, S. (1983). Directional scanning of remembered visual patterns. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*, 398–410.

Fishbein, H., Lewis, S., & Keiffer, K. (1972). Children's understanding of spatial relations: Coordination of perspectives. *Developmental Psychology*, *7*, 21–33.

Gabbard, G. O., Twemlow, S. W., & Jones, F. C. (1981). Do ''near-death experiences'' occur only near death? *Journal of Nervous and Mental Disease*, *169*, 374–377.

Ghaem, O., Mellet, E., Crivello, F., Tzourio, N., Mazoyer, B., Berthoz, A., & Denis, M. (1997). Mental navigation along memorized routes activates the hippocampus, precuneus, and insula. *Neuroreport*, *8*, 739–744.

Glicksohn, J. (1989). The structure of subjective experience: Interdependencies along the sleep–wakefulness continuum. *Journal of Mental Imagery*, *13*, 99–106.

Gouteux, S., & Spelke, E. S. (2001). Children's use of geometry and landmarks to reorient in an open space. *Cognition*, *81*, 119–148.

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*, 223–233.

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2002). Human neural systems for face recognition and social communication. *Biological Psychiatry*, *51*, 59–67.

Hintzman, D. L., O'Dell, C. S., & Arndt, D. R. (1981). Orientation in cognitive maps. *Cognitive Psychology*, *13*, 149–206 .

Huttenlocher, J., & Presson, C. (1973). Mental rotation and the perspective change problem. *Cognitive Psychology*, *4*, 277–299.

Huttenlocher, J., & Presson, C. C. (1979). The coding and transformation of spatial information. *Cognitive Psychology*, *11*, 375–394.

Irwin, H. J. (1981). The psychological function of out-of-body experiences: So who needs the out-of-body experience? *Journal of Nervous and Mental Disease*, *169*, 244–248.

Irwin, H. J. (1986). Perceptual perspective of visual imagery in OBEs, dreams and reminiscence. *Journal of the Society for Psychical Research*, *53*, 210–217.

Jellema, T., Baker, C. I., Wicker, B., & Perrett, D. I. (2000). Neural representation for the perception of the intentionality of actions. *Brain and Cognition*, *44*, 280–302.

Juurmaa, J., & Lehtinen-Railo, S. (1994). Visual experience and access to spatial knowledge. *Journal of Visual Impairment and Blindness*, *88*, 157–170.

Kerr, N. H. (1993). Rate of imagery processing in two versus three dimensions. *Memory and Cognition*, *21*, 467–476.

Kosslyn, S. M. (1980). *Image and mind.* Cambridge, MA: Harvard University Press.

Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review*, *94*, 148–175.

Kosslyn, S. M. (1991). A cognitive neuroscience of visual cognition: Further developments. In R. H. Logie & M. Denis (Eds.), *Mental images in human cognition* (pp. 351–381). Amsterdam: Elsevier Science Publishers.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 47–60.

Lea, G. (1975). Chronometric analysis of the method of loci. *Journal of Experimental Psychology: Human Perception and Performance*, *1*, 95–104.

Loomis, J. M., Blascovich, J. J., & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, and Computers*, *31*, 557–564.

Lorenz, C., & Neisser, U. (1985). Factors of imagery and event recall. *Memory and Cognition*, *13*, 494–500.

Mavromatis, A. (1987). *Hypnagogia: The unique state of consciousness between wakefulness and sleep*. London: Routledge.

May, M. (1996). Cognitive and embodied modes of spatial imagery. *Psychologische Beiträge*, *38*, 418–434.

Mellet, E., Bricogne, S., Tzourio-Mazoyer, N., Ghaëm, O., Petit, L., Zago, L., Etard, O., Berthoz, A., Mazoyer, B., & Denis, M. (2000). Neural correlates of topographic mental exploration: The impact of route versus survey perspective learning. *NeuroImage*, *12*, 588–600.

Morrs, J. R. (1987). The construction of perspectives: Piaget's alternative to spatial egocentrism. *International Journal of Behavioral Development*, *10*, 263–279.

Olofsson, U., Nyberg, L., & Nilsson, L.-G. (1997). Priming and recognition of human motion patterns. *Visual Cognition*, *4*, 373–382.

Paniaras, I. (1997). Virtual identities in computer mediated communication. *ACM SIGGROUP Bulletin*, *18*, 33–37.

Parsons, L. M. (1987). Imagined spatial transformation of one's body. *Journal of Experimental Psychology: General*, *116*, 172–191.

Péruch, P., & Gaunet, F. (1998). Virtual environments as a promising tool for investigating human spatial cognition. *Current Psychology of Cognition*, *17*, 881–899.

Piaget, J., & Inhelder, B. (1956). *The child's conception of space*. London: Routledge & Kegan Paul.

Pinker, S. (1980). Mental imagery and the third dimension. *Journal of Experimental Psychology: General*, *109*, 354–371.

Presson, C. C. (1982). Strategies in spatial reasoning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *8*, 243–251.

Presson, C. C., & Montello, D. R. (1994). Updating after rotational and translational body movements: Coordinate structure of perspective space. *Perception*, *23*, 1447–1455.

Psotka, J., Lewis, S. A., & King, D. (1998). Effects of field of view on judgments of self-location. *Presence: Teleoperators and Virtual Environments*, *7*, 352–369.

Rieser, J. J. (1989). Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 1157–1165.

Rieser, J. J., Frymire, M., & Berry, D. (1997). *Geometrical constraints on imagery and action when walking without vision*. Paper presented to the Psychonomic Society, Philadelphia.

Rieser, J. J., Garing, A. E., & Young, M. F. (1994). Imagery, action and young children's spatial orientation: It's not being there that counts, it's what one has in mind. *Child Development*, *65*, 1254–1270.

Robinson, J. A., & Swanson, K. L. (1993). Field and observer modes of remembering. *Memory*, *1*, 169–184.

Roehl, B. (1998). Internet multi-user worlds. *VR News*, *7*, 10–15.

Rolls, E. T. (1999). Spatial view cells and the representation of place in the primate hippocampus. *Hippocampus*, *9*, 467–480.

Rolls, E. T., & O'Mara, S. M. (1995). View-responsive neurons in the primate hippocampal complex. *Hippocampus*, *5*, 409–424.

Ross, J., & Lawrence, K. A. (1968). Some observations on memory artifice. *Psychonomic Science*, *13*, 107–108.

Roth, J. D., & Kosslyn, S. M. (1988). Construction of the third dimension in mental imagery. *Cognitive Psychology*, *20*, 344–361.

Sachter, J. E. (1990). *Kids'n'space: Exploration into spatial cognition of children* (Doctoral thesis). MIT Media Laboratory, Cambridge, MA.

Sachter, J. E. (1991). Different styles of exploration and construction of 3D spatial knowledge in a 3D computer graphics microworld. In I. Harel & S. Papert (Eds.), *Constructionism: Research reports and essays, 1985–1990 by the Epistemology and Learning Research Group, The Media Laboratory, MIT* (pp. 335–364). Norwood, NJ: Ablex.

Shelton, A. L., & McNamara, T. P. (1997). Multiple views of spatial memory. *Psychonomic Bulletin and Review*, *4*, 102–106.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, *171*, 701–703.

Simons, D. J., & Wang, R. F. (1998). Perceiving real-world viewpoint changes. *Psychological Science*, *9*, 315–320.

Sugiura, T. (1996). The effects of self-awareness on the internal and external viewpoints for self-imagery. *Shinrigaku Kenkyu. The Japanese Journal of Psychology*, *66*, 418–424.

Tobacyk, J. J., & Mitchell, T. P. (1987). The out-of-body experience and personality adjustment. *Journal of Nervous and Mental Disease*, *175*, 367–370.

Twemlow, S. W., Gabbard, G. O., & Jones, F. C. (1982). The out-of-body experience: A phenomenological typology based on questionnaire responses. *American Journal of Psychiatry*, *139*, 450–455.

Wachsmuth, E., Oram, M. W., & Perrett, D. I. (1994). Recognition of objects and their component parts: Responses of single units in the temporal cortex of the macaque. *Cerebral Cortex*, *4*, 509–522.

Wang, R. F., & Simons, D. J. (1999). Active and passive scene recognition across views. *Cognition*, *70*, 191–210.

Wang, R. F., & Spelke, E. S. (2000). Updating egocentric representations in human navigation. *Cognition*, *77*, 215–250.

Wells, A., Clark, D. M., & Ahmad, S. (1998). How do I look with my mind's eye: Perspective taking in social phobic imagery. *Behaviour Research and Therapy*, *36*, 631–634.

Wickens, C. D., & Backer, P. (1995). Cognitive issues in virtual reality. In W. Barfield & T. A. Furness III (Eds.), *Virtual environments and advanced interface design* (pp. 514–541). Oxford, UK: Oxford University Press.

Wraga, M., Creem, S. H., & Proffitt, D. R. (1999). The influence of spatial reference frames on imagined object- and viewer rotations. *Acta Psychologica*, *102*, 247–264.

Wraga, M., Creem, S. H., & Profitt, D. R. (2000). Updating displays after imagined object and viewer rotations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 151–168.

Yates, F. (1966). *The art of memory*. London: Routledge & Kegan Paul.

Young, M. F. (1989). *Cognitive repositioning: A constraint on access to spatial knowledge.* Unpublished dissertation, Vanderbilt University, Nashville, TN, USA.

Zacks, J., Rypma, B., Gabrieli, J. D. E., Tversky, B., & Glover, G. H. (1999). Imagined transformations of bodies: An fMRI investigation. *Neuropsychologia*, *37*, 1029–1040.

Manuscript received May 2001
Revised manuscript received May 2002