Use of virtual reality for spatial knowledge transfer: Effects of passive/active exploration mode in simple and complex routes for three different recall tasks

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Abstract

The use of virtual reality in the area of spatial cognition raises the question of the quality of learning transfer from a virtual to a real environment. Among the challenges, one is to determine the best cognitive aids to improve the quality of transfer and the conditions in which this is best achieved. The purpose of this study was to investigate the impact of passive and active exploration mode on quality of transfer in three different spatial recall tasks when the route was simple or complex.
Ninety subjects (45 men and 45 women) participated in the experiment. Spatial learning was evaluated by 3 tasks: *Wayfinding* (route reproduction in reality), *Sketch-mapping* (free hand drawing) and *Scene-classification* (make a series of pictures in chronological order) in the context of the district of Bordeaux. In the *Wayfinding* task, active learning in a Virtual Environment (VE) increased performances compared to the passive learning condition, irrespective of the route complexity factor. In the *Sketch-mapping* task, active learning in a VE induced better performances than the passive condition, but only for complex routes. In the *Picture classification* task, no benefit was observed from active learning with both simple and complex routes. These results are discussed in terms of the functional demands of the three tasks and the route complexity dimension.

Keywords: Virtual reality, Spatial cognition, Knowledge transfer, Exploration mode, Route complexity, Recall tasks.

1 Introduction

Spatial cognition refers to the cognitive processes associated with the development of a comprehensive understanding of a 3D environment and the utilization of that knowledge for various purposes. Of particular interest to us is wayfinding: navigating or learning a route in a real or virtual environment. Several studies indicate that spatial knowledge transfer from virtual to real environments is possible [*e.g.,* Witmer et al. 1996; Waller et al. 1998; Richardson et al. 1999; Foreman et al. 2000]. Efficient positive knowledge transfer occurs when the virtual environment replicates particularly relevant characteristics of the real world [Péruch and Corazzini 2003]. One of the factors identified as promoting transfer is the exploration mode in the VE. Wilson et al. [1997] distinguished two types of exploration: *active vs. passive mode*. Active exploration involves the subject's interaction with the interface (*e.g.,* joystick, glove, keyboard, etc.) while passive exploration does not. Most of the time, exploration is seen as active if the individual can move with few constraints in the VE, and it is passive when the subject is constrained to visualize a pre-determined recorded route. Some studies demonstrated a superior effect of active exploration for spatial knowledge acquisition, whereas other experiments did not demonstrate any difference, or even showed an inferior effect [for a review see Péruch and Corazzini 2003]. We examine two possible factors that could explain this inconsistency (table 1): *i*) route complexity in the environment (*e.g.,* route length, direction change); *ii*) the tasks used to measure spatial learning [Waller and Richardson 2008].

Authors	Virtual environment	Recall tasks
[Brooks et al. 1999]	Flat	- Objects Recall; - Layout Recall;
[Carassa et al. 2002]	Building (two floors)	- Wayfinding; - Pointing to the starting point; - Sketch-mapping.
[Christou et al. 1999]	Building (old)	View of route recognition: - same view as during the visualization; - new view.
[Farell et al. 2003]	Building	- Target localization; - Wayfinding.
[Gaunet et al. 2001]	Highways with villages, towns, countryside.	- Scene recognition; - Pointing to the starting point; - Sketch-mapping.
[Jinsun Hahm et al. 2007]	Rooms (four)	Objects Recognition.
[Péruch et al. 1995]	Room (with cubes)	Target localization.
[Péruch et al. 2004]	Town (district)	- Distance estimation; - Orientation judgements.
[Wilson et al. 1997]	Town (district)	- Objects Pointing; - Sketch-mapping.
	Room (with cubes)	- To find target objects; - Time.
[Wilson et al. 1999]	Town (district)	Objects Recall.
[Wilson et al. 2002]	Town (district)	- Wayfinding; - Sketch-mapping.

Table 1: A summary of studies (with adults) comparing the effects of passive *vs.* active exploration. The type of virtual environment and the recall tasks used are indicated in separate columns; tasks that revealed an advantage of active exploration are highlighted in grey.

Hence, we conducted a study to evaluate the effect of passive versus active exploration on spatial knowledge transfer according to route complexity (simple vs. complex) for three different spatial recall tasks (wayfinding, sketch-mapping, and scene classification).

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2 Method

2.1 Participants

Participants were 90 student volunteers from Victor Segalen Bordeaux 2 University (45 men and 45 women, mean age: 20 years old). All subjects were native French speakers and right-handed. Forty-five subjects participated in the Simple condition and 45 participated in the Complex condition (corresponding to Type of Route). For each condition, three groups of 15 subjects were formed according to Type of Learning (Passive Virtual *vs.* Active Virtual *vs.* Real). To balance the groups, subjects performed paper-pencil tests assessing their spatial skills, as follows: The *Survey Aptitude Test* (only parts 5 and 6) [Guilford and Zimmerman 1981]; and The *Mental Rotation Test* [Vandenberg and Kuse 1978]. There were no significant differences in performance on this test between each group.

2.2 Material

Two environments were used in our experiment, one virtual and one real (Figure 1). The real environment was an area near Bordeaux hospital, and the virtual environment (VE) was a 3D replica of that environment, created in 2006 by engineering students from the *Institut de Cognitique* using Virtools© software. Significant landmarks (*e.g.,* signpost, sign, urban furniture, etc.) as well as an auditory environment (*i.e.,* urban sounds) were included in the VE. To manipulate the exploration mode in the VE under the passive condition, participants visualized only the route without any interaction, whereas under the active condition they used a joystick offering interaction with the VE.

Figure 1: Pictures of the Bordeaux hospital, from the real environment (top) and from the VE (bottom).

The apparatus used in the virtual reality room was a Dell© personal computer (3 GHz, 5Gb RAM) with an nVidia© Quadro FX 4400 graphics card, a F1+© projector, a 2 x 1.88 meter screen (to allow immersion of the subject) and a Logitech© force 3D pro joystick for the active exploration mode. The participants were seated two meters from the display screen.

To manipulate route complexity, two route conditions were proposed:
- *Simple route*: 787 meters, 9 streets, 12 intersections, 10 direction changes;
- *Complex route*: 1457 meters, 14 streets, 18 intersections, 18 direction changes.

2.3 Procedure

The experiment procedure was as follows for each participant:
1) *Training phase* (10 min.): the subject freely explored a virtual environment that was similar to the VE used in the experiment (created by the same process but representing a different area of Bordeaux); the purpose of this phase was to allow the subject to become comfortable with using the VE technology;
2) *Learning phase of the route* (15 min. on the simple route and 25 min. on the complex route): depending on randomization, participants visualized either the *simple route* or the *complex route*. In each condition, the participants were divided into three groups according to the display mode: (*i*) *passive virtual environment* (with a route recorded) vs. (*ii*) *active virtual environment* with joystick (the route was still pre-established by the researcher who gave instructions about the direction), vs. (*iii*) the *real environment* (the participant actually traveled the route by following instructions). This latter condition was the control condition to provide the *baseline* measure for an optimal and natural spatial learning transfer (from real to real) [*e.g.,* Richardson et al. 1999; Waller et al. 2001]. The effect of passive or active exploration mode was thus measured.
3) *Test phase*: Three spatial knowledge recall tasks (presented in counterbalanced order between participants):
- *Wayfinding task in reality:* Reproduction of the route in reality (without a time limit). Participants had to replicate the learned route in reality. Direction errors and hesitations (when participants stopped and turned their heads in two different directions before walking off again) were noted. In case of error, participants were stopped and asked to take another direction. In some cases, participants made a hesitation followed by a directional error, or even made several directional errors in the same intersection. In all cases, each error or hesitation was counted.
- *Sketch-drawing task:* Freehand reproduction in the form of a sketch of the visualized route (10 min.). The required sketch was a simple outline sketch (the connected segments). The task was to indicate the directional changes and to count them.
- *Picture-classification task*: Sort a series of pictures taken along the route into chronological order (10 min.).

3 Results

For each spatial knowledge recall task, the results were analyzed with ANOVA [3 (Exploration: Passive virtual *vs.* Active virtual *vs.* Real) x 2 (Route: Simple *vs.* Complex)] with independent measures. To examine the differences between Active/Passive Virtual and Real exploration conditions, the Fisher's procedure ($p<.05$) was used for post-hoc comparisons. In addition, when an interaction effect was significant, for each route condition, partial analyses were made with a simple ANOVA analysis including the presentation factor followed post-hoc comparisons. All of the data are presented in Table2.

- *Wayfinding task in reality* - The two indicators, errors of direction and hesitations, were transformed into percentages.
For errors of direction, ANOVA analysis revealed a significant effect of Exploration [$F(2,84) = 23{,}293$; $p < .0001$] and Route [$F(1,84) = 23{,}748$; $p < .0001$]. Indeed, better performances were obtained in the simple rather than the complex route condition. Post-hoc comparisons indicated that performances were best (i.e., fewest errors) when the subjects were trained in the real world, next-best when they actively navigated in the VE, and worst when they passively moved in the VE. The interaction "Exploration x Route" was not significant ($p > .200$) indicating a similar performance pattern (*i.e.,* learning in a real environment > active learning in a VE > passive learning in a VE), irrespective of route complexity (Table 2).
For hesitations, ANOVA analysis revealed a significant effect of Exploration [$F(2,84) = 26{,}213$; $p < .0001$] and Route [$F(1,84) = 20{,}820$; $p < .0001$]. Again, better performances were obtained in the simple rather than the complex route condition. Post-hoc comparisons indicated that performances were best (i.e., fewest errors) when the subjects were trained in the real world, next-best when they actively navigated in the VE, and worst when they passively moved in the VE. The interaction "Exploration x Route" was not significant ($p > .400$), indicating a similar performance pattern (*i.e.,* learning in a real environment > active learning in a VE > passive learning in a VE), irrespective of route complexity (Table 2).
- *Sketch-mapping task* - In this task, the errors and omissions in changes of direction on the sketches were counted. Then, the score was compared to the best potential score (*i.e.,* 10 or 18 in the simple or complex route condition, respectively) to obtain percentages (Table 2). ANOVA analysis revealed a significant effect of Exploration [$F(2,84) = 35{,}287$; $p < .0001$] and Route [$F(1,84) = 13{,}390$; $p < .01$]. Indeed, better performances were obtained in the simple rather than the complex route condition. Post-hoc comparisons indicated that performances were best (i.e., fewest errors) when the subjects were trained in the real world, next-best when they actively navigated in the VE, and worst when they passively moved in the VE. The interaction "Exploration x Route" was significant [$F(2,84) = 21{,}276$; $p < .0001$]. The partial analyses and post-hoc comparisons indicated that in the simple route condition, performances were almost similar while in the complex route condition, the active virtual condition enhanced performances nearly to reach those obtained in the real condition compared to the passive condition. In other words, subjects who learned the complex route in an active VE performed much better than those who learned the same route in a passive VE (Table 2).
- *Scene-classification task* - In this task, the experimenter counted the classification errors. Then, the score was compared to the best potential score (*i.e.,* 12) to obtain percentages (Table 2). ANOVA analysis revealed a significant effect of Exploration [$F(2,84) = 57{,}064$; $p < .0001$] and Route [$F(1,84) = 85{,}707$; $p < .0001$]. Better performances were obtained in the simple than the complex route condition. Post-hoc comparisons indicated that performances were best (*i.e.,* fewer errors) when the subjects were trained in the real world compared to both passive and active exploration conditions (no significant effect between Passive and Active learning). The interaction "Exploration x Route was significant [$F(2,84) = 27{,}561$; $p < .0001$]. The partial analyses and post-hoc comparisons indicated that in the simple route condition, performances were almost similar irrespective of the exploration condition, while in the complex route condition, both active and passive virtual conditions decreased performances compared to the real condition. In other words, subjects gained no benefit from the active condition in this task (Table 2).

	SIMPLE ROUTE			COMPLEX ROUTE		
Recall Task	Passive Virtual	Active Virtual	Real	Passive Virtual	Active Virtual	Real
Wayfinding (errors)	.10*⁺ (.09)	.03* (.06)	.01 (.03)	.16*⁺ (.06)	.12* (.04)	.04 (.03)
Wayfinding (hesitations)	.08*⁺ (.07)	.04* (.06)	.00 (.00)	.15*⁺ (.06)	.09* (.04)	.03 (.03)
Sketch-map	.18 (.09)	.18 (.09)	.14 (.06)	.41*⁺ (.10)	.19 (.07)	.10 (.06)
Scene-classification	.20 (.15)	.13 (.11)	.08 (.08)	.51* (.09)	.49* (.11)	.05 (.07)

(*) Fisher's comparison (p<.05) between the (active or passive) virtual condition and the Real condition.
(⁺) Fisher's comparison (p<.05) between the active and the passive virtual condition.

Table 2: Means of Performance (%) and standard deviation in parentheses for each recall task as a function of exploration mode and route complexity factors.

4 Discussion

Our aim was to evaluate the effect of passive versus active exploration on spatial knowledge transfer according to route complexity (simple vs. complex) for three different spatial recall tasks (wayfinding, sketch-mapping, and scene classification).
First, for the Wayfinding task and whatever the indicator considered (errors or hesitations), participants performed well and made few wayfinding mistakes (all means < 20%). This indicated that good spatial knowledge transfer occurred between the virtual and real environments. Comparable findings were reported in other studies [*e.g.,* Witmer et al. 1996; Waller et al. 1998; Richardson et al. 1999; Foreman et al. 2000]. Nevertheless, the transfer from virtual to real environment remained less efficient than that provided by the control condition (from real learning to real environment). This may be accounted for by the well-known principle of appropriate processing transfer [Morris et al. 1977] where learning performance is optimized with perfect matching of learning and recall conditions. More importantly, within the Virtual conditions, active learning markedly increased the performance of the subjects for all indicators (*i.e.,* errors and hesitations) compared to passive learning. Therefore, active learning in a VE may facilitate the transfer of spatial knowledge from virtual to real environment, as suggested by several previous studies with similar findings [*e.g.,* Péruch et al. 1995; Christou and Bülthoff 1999; Carassa et al. 2002; Farell et al. 2003]. Peruch et al. [1995] proposed that recall of spatial layout was better in an active compared to a passive learning condition, as the subjects were able to respect perception-action coupling and to correlate motor and visual inputs. The better performance with active learning could therefore be due to the optimized sensori-motor integration particularly required to perform the Wayfinding task. To support this assumption, it remains to be investigated whether the interaction tool used here (*i.e.,* Joystick) played a role in terms of motivation and involvement in the task performed.
Second, for Sketch-mapping task, the benefit gained from active learning in the VE depended on the route complexity factor (*i.e.,* interaction effects). Indeed, an active learning effect was observed only when the route was complex. From the functional viewpoint, the sketch-mapping task may involve the mental simulation of action-based tasks (*i.e.,* making turns in the environment). It may be especially helpful that such turns were actually performed during learning and particularly when their

frequency of occurrence increased with the complexity of the route.
Third, in the Scene-classification task, no effect of active learning in the VE was observed, whatever the route complexity. Nevertheless, the results may be understood from a functional perspective since this task can be performed primarily through purely visually based recall (or, at least, the action component of this memory may be minimal), so there is less need to experience actions during learning.
Altogether, these findings support the view that spatial knowledge transfer occurs from virtual to real environment. This transfer can be promoted by active learning, but only when the task performances are action-based (*i.e.,* Wayfinding task) or are enhanced by action-based mental simulation, as in the case of complex routes (*e.g.,* in the Sketch-mapping task). Therefore, the functional analysis of tasks as well as route complexity seems to constitute a good way to understand the discrepant findings reported to date with regard to active/passive learning exploration. Nevertheless, more investigations are required to confirm these results, and to further investigate the relationship between exploration modes, route complexity and recall task. This would help to determine how, why and for which type of patient, virtual reality could be used in cognitive assessment and in neuropsychological rehabilitation programs of spatial capacities.

References

BROOKS, B.M., ATTREE, E.A., ROSE, F.D., CLIFFORD, B.R., LEADBETTER, A.G. 1999. The specify of memory enhancement during interaction with a virtual environment. *Memory*, 7 (1), 65-78.

CARASSA, A., GEMINIANI, G., MORGANTI, F. and VAROTTO. D. 2002. Route and survey descriptions of paths: The effect of experience of a large-scale environment. *Bulletin of People-Environment Studies*. Special Issue on Spatial Cognition.

CHRISTOU, C. G., and BÜLTHOFF, H. H. 1999. View dependence in scene recognition after active learning. *Memory and Cognition*, 27(6), 996–1007.

FARRELL, M., ARNOLD, M., PETTIFER, S., ADAMS, J., GRAHAM, T. and MAC-MANAMON, M. 2003. Transfer of route learning from virtual to real environments. *Jounal of Experimental Psychology: Applied*, 9 (4), 219–27.

FOREMAN, N., STIRK, J., POHL, J., MANDELKOW, L., LEHUNG, M., HERZOG, A. and LEPLOW, B. 2000. Spatial information transfer from virtual to real versions of the Kiel locomotor maze. *Behvaiour Brain Research*, 112, 53-61.

GAUNET, F., VIDAL, M., KEMENY, A. and BERTHOZ, A. 2001. Active, passive and snapshot exploration in a virtual environment: Influence on scene memory, reorientation and path memory. *CognitiveBrain Research*, 11, 409-420.

GUILFORD, J.P and ZIMMERMANN, W.S. 1981. *Guilford-Zimmerman Aptitude Survey: Manual of instructions and interpretations*. Minneapolis : Consulting psychologists press.

JINSUN HAHM, M.A, KANGHEE LEE, M.A., SEUNG-LARK LIM, M.A., SEI-YOUNG KIM, B.A., HYUN-TAEK K. and JANG-HAN, L. 2007. Effects of active navigation on object recognition in virtual environments. *Cyber Psychology & Behavior*, 10 (2), 305-308.

MORRIS, C., BRANSFORD, J., and FRANKS, J. 1977. Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior*, 16, 519-533.

PERUCH, P., VERCHER, J.L. and GAUTHIER, G.M. 1995. Acquisition of spatial knowledge through visual exploration of simulated environments. *Ecological Psychology, 7 (1)*, 1-20.

PERUCH, P. and CORAZZINI, L.L. 2003. Se déplacer et naviguer dans l'espace. *In* J. Fuchs, G. Moreau & J.P. Papin (Eds.), Traité de la réalité virtuelle, (pp. 189-208). Nantes : Les Presses de l'Ecole des Mines.

PERUCH, P. and WILSON, P. 2004. Active versus passive learning and testing in a complex outside built environment. *Cognitive Processing*, 5, 218–227.

RICHARDSON, A. E., MONTELLO, D. R. and HEGARTY, M. 1999. Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory and Cognition*, 27(4), 741–50.

VANDENBERG, S. G. and KUSE, A. R. 1978. Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, 47 (2), 599–604.

WALLER, D., HUNT, E. and KNAPP, D. 1998. The transfer of spatial knowledge in virtual environment training. *Presence: Teleoperators and Virtual Environments*, 7, 129-143.

WALLER, D., KNAPP, D. and HUNT, E. 2001. Spatial representations of virtual mazes: the role of visual fidelity and individual differences, *Human Factors*, 43 (1), 147-158.

WALLER, D. and RICHARDSON, A.R. 2008. Correcting distance estimates by interacting with immersive virtual environments: effects of task and available sensory information. *Journal of Experimental Psychology: Applied*, 14 (1), 61-72. 2008

WILSON, P.N., FOREMAN, N., GILLET, R. and STANTON, D 1997. The effect of landmarks on route-learning in a computer-simulated environment. *Journal of Environmental Psychology,* 14, 305-313.

WILSON, P.N. 1999. Active exploration of a virtual environment does not promote orientation or memory for objects. *Environment and Behavior*, 31 (6), 752-763.

WILSON, P. and PERUCH, P. 2002.The influence of interactivity and attention on spatial learning in a desk-top virtual environment. *Current Psychology of Cognition*, 21, 601-633.