frontiers

A Virtual Reality-Based Tool to Investigate Spatial Planning

Déborah A. FOLOPPE[1, 2*], Paul RICHARD[1], Philippe ALLAIN

[1] Laboratoire Angevin de Recherche en Ingénierie des Systèmes (LARIS), University of Angers, France
[2] Laboratoire de Psychologie des Pays de la Loire (LPPL), University of Angers, France

***Correspondence:**
Déborah A. Foloppe
deborah.foloppe@univ-angers.fr

Keywords: Virtual Reality, Zoo Map Test, Neuropsychology, Planning, Spatial Cognition

Abstract

The early neuropsychological assessment tools have been developed with the construct validity of the measure as a primary consideration. Such traditional tests are known to provide objective and standardized measure. However, they use specialized and decontextualized exercises which break the functioning unity of the multiple cognitive capacities. Thus, tests based on process-oriented exercises have been developed, such as the Zoo Map Test. By soliciting various capacities to solve a practical problem, this test brings an interesting framework to assess multiple aspects of the planning. This test has shown its usefulness in various clinical populations. However, additional investigations are needed to understand planning behaviors in more details and measure them with improved accuracy and ecological validity. To his end, we converted this paper-and-pencil test into a Virtual Reality-based assessment tool of planning. This paper describes the difficulties and the limits as well as the new opportunities in converting a 2D map consisting of roads and places into a 3D virtual environment.

1 Background

The early neuropsychological assessment tools have been developed with the construct validity of the measure as a primary consideration. Such traditional tests are known to provide objective and standardized measure. However, they use specialized and decontextualized exercises which break the functioning unity of the multiple cognitive capacities (Wilson et al., 1997). Thus, tests based on process-oriented exercises have been developed, such as the Zoo Map Test (ZMT, a subtask derived from the Behavioral Assessment of the Dysexecutive Syndrome test battery, Wilson et al., 2003).

The ZMT provides a friendly, meaning full and credible scenario. In the ZMT, participants are given a map of a zoo with written instructions, which indicate the places to visit (e.g., elephant house, lions cage) and the rules to follow (e.g., starting at the entrance and finishing at a designated picnic area, using some paths only once). It is performed though two conditions, each associated to a specific way to indicate the places to visit. In the first "formulation" condition, the places are randomly listed. The high demand condition assesses the ability to independently formulate and execute a plan without external guidance. In the second "execution" condition, the places are written in an indicated prescribed order of the visit. This low demand condition assesses the ability to execute a high guided concrete external strategy.

By soliciting various capacities to solve a practical problem, this test brings an interesting framework to assess multiple aspects of planning. The ability to plan is an important ability for our everyday autonomy. Planning involves the capacity for maintaining goal-directed behavior through dependence on rule adherence. It requires executive abilities, such as target identification/selection, strategic decisions making for sequencing, serial ordering of task steps (plan formulation), initiating and executing the planned actions are monitoring the goals (plan execution).

The ZMT has shown its usefulness in various clinical populations. However, some studies have found similar profiles in patients with MCI and healthy elderly (Allain et al., 2009) while other studies found similar profiles in MCI and Alzheimer's disease (da Costa Armentano et al., 2009). Other studies have reported a lack of sensibility to distinguish patients with a brain injury and healthy subjects (Eslinger and Damasio, 1985; Wood and Liossi, 2006; Wood and Rutterford, 2004), a lack of correlation between the performance on ZMT and the score on Dysexecutive Questionnaire in patients with a brain injury (Wood and Liossi, 2006), or a lack of correlation between the performance on ZMT and various domains of participation (e.g., leisure, transportation, residence, Bar-Haim Erez et al., 2009).

Many aspects of the paper-and-pencil nature of the ZMT may affect the predictive value of the measure of planning behaviors in the real life and the autonomy level, especially for the executive components such as monitoring or regulation, as found in other traditional tests such as the Copy of the Rey-Osterrieth Complex Figure and the Porteus Maze (Chaytor and Schmitter-Edgecombe, 2003; Ready et al., 2001). Indeed, ZMT focus on planning in small spaces, soliciting a few working memory (spatial visualization) since executed steps are drawn. In addition, for familiar cases such as IADL, episodic memory plays an important role that the ZMT may fail to engage.

2 Tool

2.1 Hypothesis

Because additional investigations are needed to understand planning behaviors in more details and measure them with improved accuracy and ecological validity, we converted the paper-and-pencil ZMT into a Virtual Reality (VR) -based assessment tool: the V-ZMT. We hypothesized that a material with a higher verisimilitude, especially in the practical execution phase, will bring a better measure and a better understanding of perceived difficulties and participation. This is in the same vein as the Wisconsin Card Sorting Test has been integrated in a 3D building with interactive doors (Pugnetti et al., 1998). The ecological validity is maximized by the spatial-temporal continuity (i.e., 3D and real time), multimodal information, realistic interactions, and credible scenarios, while behavior is objectively recorded (e.g., pressure time, distractors, complexity of stimuli, Klinger et al., 2006; Schultheis et al., 2002).

2.2 Design

The first consideration was to convert a 2D map consisting of roads and places into a 3D virtual environment, in the respect of ratio scale of the classical map. The system has been developed using the Unity3D game engine which allows to manage 3D models and C# scripts, and to compile the code into a program runnable on Microsoft Windows. The 3D models have been created with 3DS Max. The working flow is presented in the **Figure 1**. Virtual environment includes 3D models easy to recognize (e.g., coffee place, animals) and each place was associated to a specific sound. The V-ZMT keeps a maximal fidelity with the original one. We obtained a simulation tool to cognitively plan and execute a path (see **Figure 2** for screenshots).

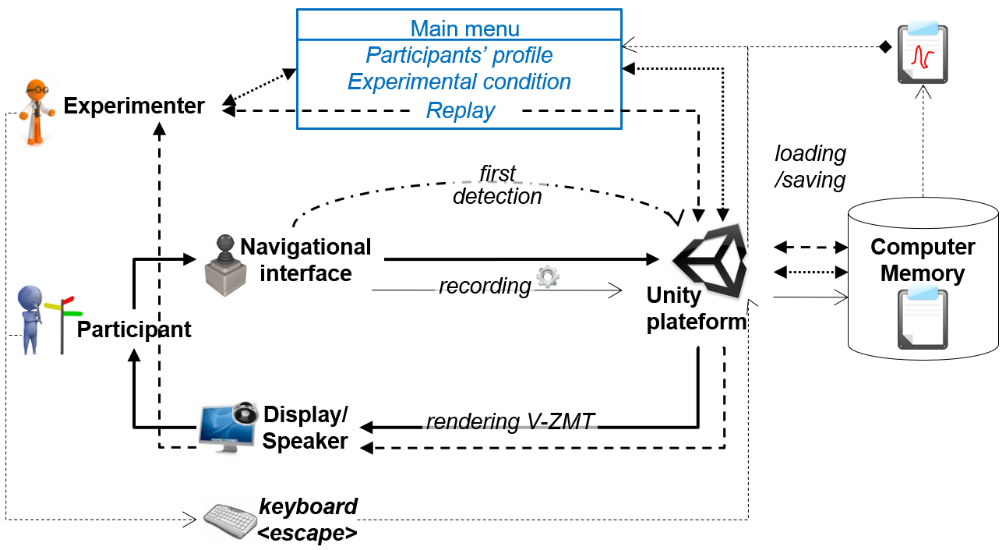

Figure 1. Working flow of our V-ZMT.

However, adaptations to a VR based form lead to some notable differences. Indeed, with the first-person navigation, spatial relationships are not visually available all at the same time, making difficult or impossible to anticipate and order the places for the visit as asked in the ZMT. We consequently added a 2D top-view mini-map of the environment, which corresponds to the "cognitive maps" used to represent spatial information and navigate in the environment (Tolman, 1948). To discharge the working memory, a pointer can be displayed to indicate the current position. In addition, because this navigation condition requires to translate allocentric spatial information from the 2D map into egocentric spatial relationships in the 3D navigated V-ZMT, we designed an alternative, GPS-like map, showing the schematic virtual world from the first-person view. For the navigation in-virtuo, we added signs and tree so that, from any point of the map, the next reachable places are visible and indicated by signs, while the other places are masked by trees. However, in the V-ZMT, participant automatically starts at the entrance, and hence it is not possible to break.

The main outcome measures include the number of places successfully visited, the number of rules violated, the plan formulation time (which begins at the end of the instructions presentation and ends of the task initiation), and the execution time. Our tool also gives a better way to the investigate formulation versus execution, because it also gives the time spend to look the virtual map during the execution part. It may view as a distanced) Several other outcome measures can be easily implemented, such as the sequencing score, deviations from the roads, failure to make a continuous line, inappropriate places.

2.3 Use cases

The original ZMT is used by researchers in Neuropsychology to investigate planning in various populations such as Alzheimer's disease, schizophrenia, Huntington disease, or autistic syndromes. The V-ZMT may help in early dementia screening or shown problems not detected using the paper-and-pencil version in brain injured patients.

Interactive device and interaction can be modified to be adapted to the patient, reducing the interaction or allowing a full and complete interaction. These features can be customized to generate many experimental conditions by changing places to visit (formulation condition), order (execution condition), nature of spatial information displayed on the mini-map and signs (verbal, iconographic, or verbal+iconographic), language, navigation interface (joystick) and options (e.g., speed, side moves). By default, the virtual environment is a zoo, instructions about places to visit are written, in French, as in the first part of the test, the mini-map is a 2D top-view map, the three rules are given, the interactive device is the keyboard, and the speed velocity constant.

Figure 2. Top view of the V-ZMT.

3 Conclusion

We developed a virtual reality version of a the Zoo Map Test, the V-ZMT, initially designed to understand planning behaviors in more details and measure them with improved accuracy and ecological validity. In a near future, I would to investigate planning in a such large space versus planning in instrumental activities of daily living (small space), especially regarding the orientation abilities and visualisation abilities. This tool can also be used to test different navigation techniques.

4 References

Allain, P., Ledru, J., Granger, C., Annweiler, C., Chauviré, V., Etcharry-Bouyx, F., et al. (2009). P3-21 Fonctions exécutives et maladie d’Alzheimer : Intérêt du «Tinker Toy Test» pour prédire l’autonomie. *Rev. Neurol. (Paris).* 165, 77. doi:10.1016/S0035-3787(09)72649-9.

Bar-Haim Erez, A., Rothschild, E., Katz, N., Tuchner, M., and Hartman-Maeir, A. (2009). Executive functioning, awareness, and participation in daily life after mild traumatic brain injury: A preliminary study. *Am. J. Occup. Ther.* 63, 634–640. doi:10.5014/ajot.63.5.634.

Chaytor, N., and Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognition skills. *Neuropsychol. Rev.* 13, 181–197.

da Costa Armentano, C. G., Porto, C. S., Maria, S., Brucki, D., and Nitrini, R. (2009). Study on the Behavioural Assessment of the Dysexecutive Syndrome (BADS) performance in healthy individuals , Mild Cognitive Impairment and Alzheimer ' s disease: A preliminary study. *Dement. Neuropsychol.* 3, 101–107. doi:10.1590/S1980-57642009DN30200006.

Eslinger, P. J., and Damasio, A. R. (1985). Severe disturbance of higher cognition after bilateral frontal lobe ablation: Patient EVR. *Neurology* 35, 1731–1731. doi:10.1212/WNL.35.12.1731.

Klinger, E., Marié, R. M., and Viaud-Delmon, I. (2006). "Applications de la réalité virtuelle aux troubles cognitifs et comportementaux," in *Traité de la réalité virtuelle*, ed. P. Fuchs (Paris, France: Les Presses de l'École des mines), 119–156.

Pugnetti, L., Mendozzi, L., Attree, E. A., Barbieri, E., Brooks, B. M., Cazzullo, C. L., et al. (1998). Probing memory and executive functions with virtual reality: Past and present studies. *Cyberpsychology Behav.* doi:10.1089/cpb.1998.1.151.

Ready, R. E., Stierman, L., and Paulsen, J. S. (2001). Ecological validity of neuropsychological and personality measures of executive functions. *Clin. Neuropsychol.* doi:10.1076/clin.15.3.314.10269.

Schultheis, M. T., Himelstein, J., and Rizzo, A. a (2002). Virtual reality and neuropsychology: Upgrading the current tools. *J. Head Trauma Rehabil.* 17, 378–394.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychol. Rev.* 55, 189. Available at: http://psycnet.apa.org/journals/rev/55/4/189/ [Accessed May 10, 2011].

Wilson, B. A., Alderman, N., Burgess, P., Emslie, H., and Evans, J. J. (2003). Behavioural Assessment of the Dysexecutive Syndrome (BADS). *J. Occup. Psychol. Employ. Disabil.* 5, 33–37. doi:10.1080/09602010802622730.

Wilson, P. N., Foreman, N., Gillett, R., and Stanton, D. (1997). Active versus passive processing of spatial information in a computer-simulated environment. *Ecol. Psychol.* 9, 207–222. Available at: http://www.informaworld.com/index/784403895.pdf [Accessed May 10, 2011].

Wood, R. L., and Rutterford, N. A. (2004). Relationships between measured cognitive ability and reported psychosocial activity after bilateral frontal lobe injury: An 18-year follow-up. *Neuropsychol. Rehabil.* 14, 329–350. doi:10.1080/09602010343000255.

Wood, R., and Liossi, C. (2006). The ecological validity of executive tests in a severely brain injured sample. *Arch. Clin. Neuropsychol.* 21, 429–437. doi:10.1016/j.acn.2005.06.014.

5 Acknowledgements

I thank Barbara Wilson and Sarah Weinberg for the permission to use their material.

6 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.