A Virtual Reality-Based Tool to Investigate Spatial Planning

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

2 [1] Laboratoire Angevin de Recherche en Ingénierie des Systèmes (LARIS), University of Angers,
3 France
4 [2] Laboratoire de Psychologie des Pays de la Loire (LPPL), University of Angers, France

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

9 **Abstract**

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

21 **1 Background**

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

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

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

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

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

2 Tool

2.1 Hypothesis

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

2.2 Design

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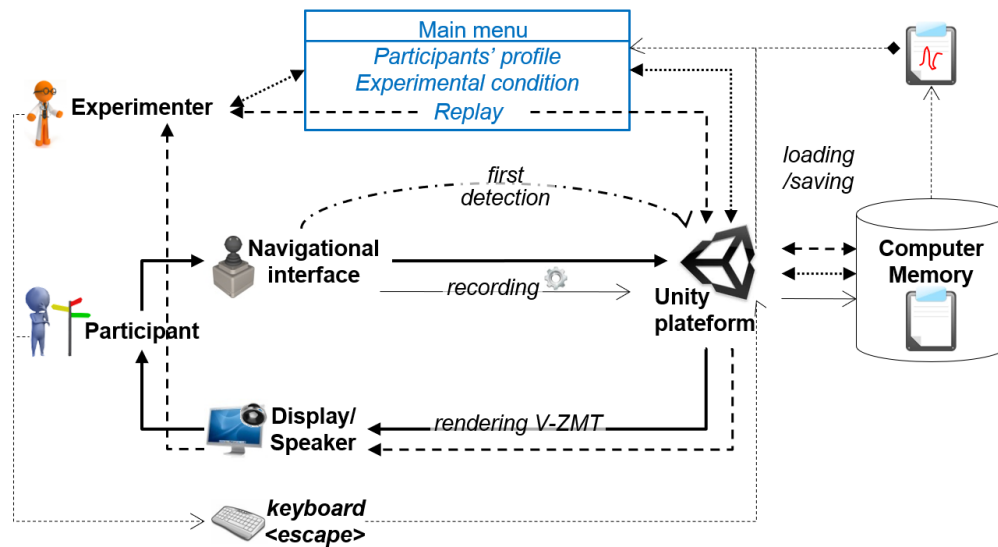78 execute a path (see **Figure 2** for screenshots).

79

Figure 1. Working flow of our V-ZMT.

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

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

100 **2.3 Use cases**

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

105 Interactive device and interaction can be modified to be adapted to the patient, reducing the interaction
106 or allowing a full and complete interaction. These features can be customized to generate many
107 experimental conditions by changing places to visit (formulation condition), order (execution
108 condition), nature of spatial information displayed on the mini-map and signs (verbal, iconographic, or

109 verbal+iconographic), language, navigation interface (joystick) and options (e.g., speed, side moves).
110 By default, the virtual environment is a zoo, instructions about places to visit are written, in French, as
111 in the first part of the test, the mini-map is a 2D top-view map, the three rules are given, the interactive
112 device is the keyboard, and the speed velocity constant.

113

114 **Figure 2.** Top view of the V-ZMT.

3 Conclusion

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

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161 **6 Conflict of Interest**

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