Assessing spatial navigation in seniors and clinical settings: Stepwise progression from real-world to VR

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***Abstract*—Deficits in spatial navigation are difficult to assess in older adults and neurological patients since available clinical tests lack ecological and construct validity. Experimental paradigms, on the other hand, are often too complex to administer in a cognitively impaired population or require lengthy instructions, hindering the application in daily clinical practice. We introduce different developmental stages of a passive navigation paradigm, inspired by everyday difficulties of patients, from real-world stimuli to an optimized VR adaptation. The respective data in healthy seniors shows desirable psychometric properties and associations with cognitive measurements, e.g. working memory and mental rotation, support the construct validity of the assessment. Future studies will address the feasibility of this paradigm in patients with mild cognitive impairment (MCI).**

Keywords—navigation; old age; MCI; assessment; virtual reality

I. Introduction

Spatial navigation can be defined as the ability to find your way from one place to another. It is commonly impaired in various neurological disorders and thought to decline in healthy aging [1, 2]. Previous studies showed that it can be used to differentiate between different types of dementia [3]. In clinical assessments, spatial navigation abilities are often approximated by testing mental rotation or visuoconstruction, artificially isolating aspects of navigation. In contrast, experimental paradigms using desktop and immersive VR designs provide higher ecological validity. However, their complexity limits the use in cognitively impaired populations and performance can be confounded by diverging skills in operating the control device. Here, we therefore introduce an assessment combining ecological validity and transgenerational applicability.

II. METHOD

A. Paradigm

Four versions of a recently developed passive spatial navigation paradigm are presented, which simulate the everyday task of finding a room in a building using a map. Participants watch videos showing the egocentric viewpoint of a person exploring different hallway sections alongside the respective map (for an example see Fig. 1). At the end of each video, the person opens one of the doors in the hallway. The hallway map indicates starting point, hallway structure and the location of the doors. The participant's task is to mentally trace the position of the person in the video using the map and to identify the door on the map corresponding to the chosen door at the end of the video. In study one, the paradigm was initially implemented using videos of real-world hallways. In study two, the task was implemented in VR comparing a replication and an adaptation of the real-world stimuli. The third study used the final optimized VR version of the paradigm, which consists of 12 trials of increasing difficulty.

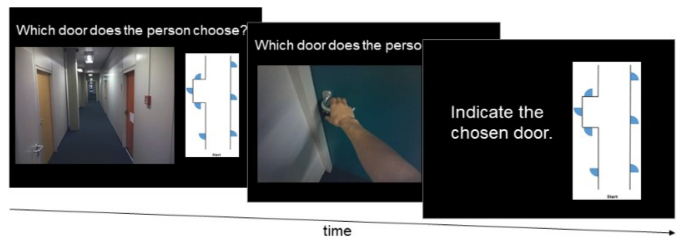

Fig. 1. Schematic representation of a single trial: A simultaneous presentation of a video showing an egocentric exploration of real-world hallways and the associated allocentric map.

The VR environment was created with *Blender* and *Unity*. The task is presented on a computer screen and requires 15 min including pre-test, instruction and practice trials. In study two, an exact virtual replication of the real-world hallways, only controlling for distractors (e.g. diverging colors and lighting), was compared to an adapted virtual version. The latter consists of hallways similar to the real-world videos, but with accurately mirrored layouts (see Fig. 2). Beyond the binary distinction whether the participant succeeded in a trial or not, the mirrored layout of the adapted virtual hallways allows a differentiation of the distinct deficits underlying an impaired navigation performance, by capturing mental rotation and updating errors.

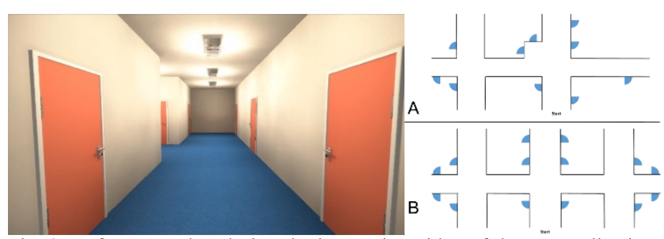

Fig. 2. Left: Screenshot during the instruction video of the VR replication of the real-world environment. Right: Different versions of maps in trial eight for the replication and real-world hallways (A) and the adapted map with accurately mirrored layouts (B), used in the adaptation and final version.

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B. Participants

The first study, using real-world hallways, employed a sample of 35 healthy older adults (26 female) with a mean age of 68.6 years (SD = 5.7, range 56-78 years). Study two, comparing the VR replication and adaptation, included 31 healthy seniors (21 female) with a mean age of 70.0 years (SD = 6.1, range 62-85 years). Preliminary analysis of the third study, using the final VR version, was conducted on 68 of the aimed at 80 healthy participants (49 female). This sample had a mean age of 66.9 years (SD = 9.3, range 50-85 years).

C. Additonal behavioural measurements

A detailed neuropsychological assessment was conducted with each participant of study one and three. It included tests for general cognitive ability, visuoconstruction, visuo-spatial short-term, working and episodic memory, selective attention, executive functions and mental rotation. In addition, participants filled out questionnaires regarding demographics, depressiveness, subjective cognitive complaints and sense of direction.

III. Preliminary Results

In study one, test scores in the real-world task showed a normal distribution (Shapiro-Wilk test for normality: $W = 0.97$, $p = .580$), they were sensitive to age, gender, education and they showed significant relationships with working memory and mental rotation, but not with measurements for visuo-spatial episodic memory (see *Table 1*). The comparison of the VR replication and adaptation in study two showed that both were feasible to apply in older adults, with slight ceiling effects in both versions, which were more prominent in the replication. Scores in the adaptation, were also normally distributed (Shapiro-Wilk test for normality: $W = 0.94$, $p = .279$), pointing towards a non-inferiority of the adaptation. In order to avoid ceiling effects in the third study, two more complex trials were added for the final version of the navigation paradigm.

TABLE I
Relationships of Test Scores in Study One with Demographic and Cogntive Parameters Including Test Statistics.

Variable	Effect size	t(df)/ S	p	Power (1-β)
Age	$r = -.53$	t (33) = -3.61	.001	.95
Gender	$d = 1.43$	t (33) = 3.45	.002	.95
Education	$r_s = .42$	$S = 4143.5$	.012	.76
Working memory	$r_s = .44$	$S = 4020.1$	.009	.80
Mental rotation[a]	$r = .36$	t (33) = 2.24	.032	.60
Episodic memory	$r = .32$	t (32) = 1.94	.062	.49

a. Correlation with a subset of items with at least one rotation.

Preliminary data of study three showed that the 68 healthy participants performed in the upper range of possible test scores. Performance was approximately normally distributed (Shapiro-Wilk test for normality: $W = 0.97$, $p = .072$; see Fig. 3), and showed significant correlations with age ($r = -.41$, t (66) = -3.60, $p < .001$, Power (1-β) = .95) and years of education ($r_s = .32$, $S = 35643$, $p = .008$, Power (1-β) = .78), but did not differ between males and females ($p = .386$). As shown in Fig. 3, higher performance was also associated with a better self-reported sense of direction ($r = .30$, t (66) = 2.56, $p = .013$, Power (1-β) = .72).

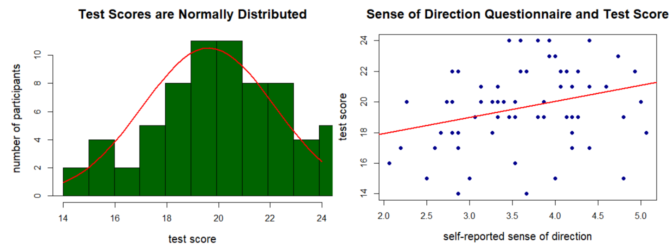

Fig. 3. Left: Histogram of the frequency distribution of the test score. The red line is indicating normal distribution. Right: Scatterplot and regression line illustrating the positive relationship of the score in the new navigation paradigm with self-reported sense of direction.

Test scores showed significant correlations with various measurement assessing spatial cognition. Fig. 4 illustrates the association with working memory performance ($r_s = .49$, $S = 26866$, $p < .001$, Power (1-β) = .99) and the relationship of the number of mental rotation errors with performance in a mental rotation task ($r_s = .29$, $S = 35633$, $p = .016$, Power (1-β) = .69).

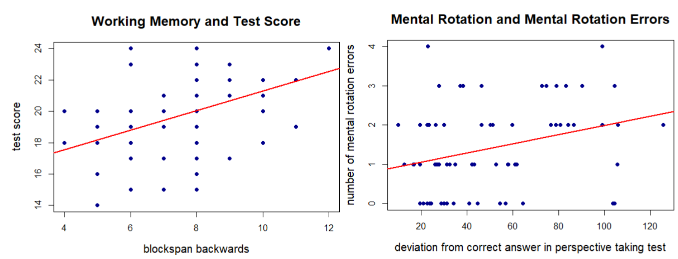

Fig. 4. Scatterplots and regression lines showing the positive associations of the test score with working memory, operationalised using a block tapping task (left) and the number of mental rotation errors and mental rotation performance, operationalised using a perspective taking test (right).

IV. Discussion

Preliminary results of the final VR version support the construct validity of the task and show that the VR implementation allowed for an identification of different error-types. Furthermore, the distribution of the test scores is promising for the following application in MCI patients, since the test score distribution leaves room for capturing lower performances without floor effects. Given that participants do not actively navigate the environment using a controller, the paradigm also controls for potential motor deficits and general ability to operate control devices. The combination of transgenerational acceptance with the versatile applicability of VR offers a feasible and an ecologically valid approach for a differential assessment of spatial navigation, specifically in older participants and patients.

References

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