ANTaging: a Research Protocol for Active Navigation Training with Virtual Reality in Mild Cognitive Impairment

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Abstract. Navigation is a multimodal process that requires the active computation of cognitive and bodily cues along with external environmental information. Indeed, according to the embodied cognition framework, the body and the environment build our cognitive representation of the space. This view is supported by findings in the aging population where the decline of bodily information accounts for the deficits in spatial navigation. Consequently, it is crucial to develop innovative rehabilitation solutions in aging that require the active use of bodily and cognitive processing of the space and its elements. Mild cognitive impairment is a geriatric syndrome considered to be a transitional stage between normal aging and dementia. Consequently, it is a preferred time window to administer cognitive rehabilitation programs that could slow down cognitive deterioration. In the current paper, the ANTaging protocol will be presented in its three-step studies: pilot testing, usability study, and proof-of-concept trial.

Keywords. Navigation, Spatial Memory, Embodiment, Virtual Reality, Mild Cognitive Impairment, Rehabilitation

1. Introduction

According to the framework of embodied cognition, the sensorimotor system helps to define the cognitive representations of the space (1). Indeed, navigation is a complex behavior that implies the active use of bodily and cognitive cues. Idiothetic information (e.g., motor commands, vestibular system, and proprioception), decision-making (e.g., route planning), spatial attention, and spatial information manipulation (e.g., mental rotation) are actively involved during navigation (2). Conversely, during passive navigation, we only use visual information (2). During landmark-based navigation, environmental cues (i.e., landmark, boundaries) help in addition to bodily information to encode and remember locations according to egocentric (i.e., relations dependent to the body) and allocentric (i.e., relations independent from the body) spatial reference frames (3).

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The crucial role of the body during navigation is also supported by evidence showing alterations in aging and dementia, where both bodily and cognitive functions decline and affect spatial navigation and memory (4,5). A crucial stage for administering cognitive rehabilitation to slow down cognitive deterioration is mild cognitive impairment (MCI), which is considered a transition stage between aging and dementia (6).

Virtual reality (VR) could be the preferred candidate for studying and training navigation and memory within an embodied framework in aging. In particular, Tuena and colleagues (7) suggest that by means of immersive VR interventions for spatial memory it is possible to actively tap cognitive and bodily cues through the virtual bodily representation (the involvement of idiothetic information used with immersive VR devices), the spatial affordances (environmental cues coded as action possibilities), and the virtual enactment effect (8) (spatial memory enhancement provided by actively interacting, bodily and/or cognitively, with the virtual space). Indeed, for the spatial memory rehabilitation enhancement, it is suggested for MCI patients to: 1) provide them with a high degree of idiothetic involvement (i.e., immersive VR), 2) use directional aids and salient landmarks as visual cues, and 3) apply an active (cognitive and bodily) navigation task (7).
Here we present the research protocol (Italian Ministry of Health; SG-2018-12368175) of ANTaging (Active Navigation Training: an innovative embodied-based training system for spatial navigation in aging).

2. Method

2.1. Protocol Design

ANTaging is a proof-of-concept trial aiming at developing an embodied VR system for active landmark-based navigation rehabilitation in patients suffering from MCI. It consists of three study phases: 1) pilot testing of five navigation interfaces, 2) usability study, and 3) experimental trial. The pilot testing will involve immersive and non-immersive virtual environments to investigate the impact of active navigation cues and passive navigation on allocentric and egocentric frames. The usability study will test the ease of use of the CAVE system for navigation rehabilitation purposes. Lastly, the proof-of-concept trial will test the efficacy of the CAVE active training against the treatment as usual (TAU). The project is approved by the Ethics Committee of the Istituto Auxologico Italiano and participation is possible only after the consent form signature.

2.2. Participants

According to a previous VR navigation training effect size (9), the minimum sample size (GPower) is 32 participants in total for the trial. Participants satisfying the core clinical criteria for MCI (6) will be recruited.

2.3. Materials

For the pilot study, the Oculus Rift S and the 3dRudder foot-motion pad (https://www.3drudder.com/) will be used to navigate in an immersive VR scenario. VR-ready PC and keyboard keys will be used to interact with non-immersive environments. Lastly, the CAVE will be integrated with 3dRudder, 3D glasses, and joypad for the active VR navigation training (usability study and trial).

2.4. Measures

2.4.1. Pilot testing

A short neuropsychological assessment battery (global cognition and visuospatial memory) and functional (ADL and depression) will be administered. Additional clinical information will be gathered such as the etiology and phenotype of MCI (6). During the assessment of spatial memory, VR data (measures of time and error) at recall will be saved. Error is calculated as the distance between the actual and recalled position of each object previously learned.

2.4.2. Usability Study

To assess the usability, qualitative and quantitative approaches will be applied as suggested (10). System usability scale (SUS) (11), thinking-aloud procedure, presence (12), and cybersickness questionnaire (12) will be used in this study.

2.5. Trial

Trial assessment will consist of three-time points: baseline, post-test, and three months follow-up. A comprehensive neuropsychological battery (e.g., (9)) will be administered. Recall VR data will be saved in each session.

2.6. Procedures

2.6.1. Pilot testing

To assess egocentric and allocentric landmark-based spatial memory and navigation, an object location task based on landmark and boundary recall will be used (3). In a 50m (virtual units) circular pen, patients have to learn the location of four objects (suggested memory span for MCI; (13)) by using an intra-arena landmark (pillar), the boundary (fence), and distal cues (mountain range, clouds). The pillar supports egocentric spatial memory, whereas the fence the allocentric one. Objects will randomly appear one at time; to see the following object, the patient must go to the exact location of the item. Once over it, the object disappears and he/she must find the next one. Each object is presented four times in a random order (3). In the immediate recall phase, each item is randomly presented to the patient. He/she must place the object where it was previously picked in the pen. Randomly, the pillar or the fence are presented to force the use of egocentric or allocentric recall strategies. Each object is tested two times with the pillar and with the fence (eight trials for each spatial frame) (3).

Participants will undergo two experimental sessions (1hr; 2-3 days distance) where egocentric and allocentric spatial memory will be tested with five navigational interfaces (passive, immersive, map, decision-making, and spatial-attentive). In the sensorimotor session, the passive and immersive interfaces are tested, whereas in the cognitive session, the remaining three are used. The two sessions are counterbalanced across participants, and within each session, interfaces are randomized. In each condition, four objects are randomly picked from a list of eight. Living and non-living categories of items are balanced in each random pick.

In the “immersive” condition, participants navigate in the learning phase using a 3D visor and 3dRudder with the use of directional cues (a line to follow to reach the item) and no use of the map or attentional cues. This is done to isolate the idiothetic component. In the recall phase, the same VR apparatus is used; directional cues, map, or attentive cues are not provided. In the “passive” condition, participants simply watch on the PC screen the navigation made by the experimenter (no map, directional, and attentive cues). This is done to isolate the visual system only in a passive manner (2).

In the cognitive session, 2D VR is used (PC screen and keyboard keys) to minimize the involvement of idiothetic information. In the “map” condition, the participant navigates with an interactive map of the pen and directional cues but no attentional cues. This is done to isolate the manipulation of spatial information. In the recall phase, none of the cues are provided: the participant uses keys to replace the items. In the “spatial-attentive” condition before the learning phase, the participant is in the middle of the pen with the pillar, fence, and distal cues, and (s)he is asked to look around with the arrow keys, find some orange markers, and say aloud the number showed in each marker. Markers are placed like so: one on the pillar, one on the mountain range, and four on the top of the fence (circularly equidistant). Once all the markers are found, the experimenter makes them disappear. The patient starts the learning phase with directional cues but no map. This condition forces the use of attentive resources to the spatial layout and environment before starting the encoding phase. At recall, cues are not given. Lastly, in the "decision-making", directional cues are removed and no map nor attentive cues are displayed. In this sense, the participant can freely decide where to go. In the recall phase, no cue is used. To motivate the patients, instructions are written as a story, where they are asked to help a little girl to collect and replace the items in the pen.

2.6.2 Usability Study

For usability and the trial, the environment is a city square. The usability session lasts 30 minutes and participants are asked to carry out simple tasks in the CAVE. The thinking-aloud procedure is applied during tasks' execution. The participant, by using the 3dRudder and joypad, must find, collect, and replace one item in the square. Comments, thoughts, and non-verbal expressions are written in the thinking-aloud grid. After this part, SUS, presence, and cybersickness questionnaires are administered.

2.7. Trial

In the trial, patients will be randomly allocated (1:1 ratio) to the VR and TAU groups. The two programs will consist of ten training sessions (max 1hr; length: 3-4 weeks) with pre-post and 3 months follow-up testing. Both pieces of training are of increasing difficulty and follow the method of decreasing assistance (14). The TAU consists of "paper and pencil" training for visuospatial memory used at the Rehabilitation Unit (Istituto Auxologico Italiano). In the VR group, participants have to learn four object-locations (see 2.6.1 for details) in a circular square of a city with intra-arena landmark (obelisk), boundary (arcade), and distal cues (clouds, mountains). In the encoding phase, the patients will actively navigate with 3dRudder in the CAVE scenario. Suggested aids to help encoding are directional (15) and attentional cues (16) but not map (15) (see 2.6.1 for description). During recall, patients must reset one object at time (see 2.6.1 for details). The order of obelisk and arcade cues is counterbalanced across sessions (e.g., recall phase session one; O-A-O-A; recall phase session two: A-O-A-O). In the recall phase, the decreasing assistance method is applied as follows during the ten sessions: in the first trial of the first five sessions, the patient is asked to search for a marker showing the position of the object he/she has to put back. In the following trials, the participant must put back each object where he/she thinks it was. When the patient is on the retrieved location, the marker of the correct position is showed and feedback is provided concerning the correct location. The first five sessions are used to recall without errors the position of the items presented. From the 6th session to the last one, in the first trial, the participant must put back each object where he/she thinks it was. When the patient is on the retrieved location, the marker of the correct position is showed and feedback is provided concerning the correct location. In the remaining trials, the patient is only given computerized feedback ("well done": correct response if he/she puts back the item within a ratio of 6.5 virtual units; otherwise "try again, the response is incorrect"). VR data for egocentric and allocentric memory will be calculated only for the last five sessions (first trial with feedback excluded).

3. Expected Results

We expect that in the pilot testing, the map will not be useful for MCI (15) and that passive navigation will be worse compared to the other conditions (8). We also hypothesize that allocentric memory will be improved by idiothetic cues (17), egocentric memory will decrease with no directional cues (15), and allocentric frame will benefit from attentional cues (18). In our embodied active navigation training, we expect to observe an improvement in egocentric and allocentric memory in the last five sessions (VR data) in the VR group, and an improvement at post-test, and possibly at the follow-up, in long-term visuospatial memory and mental rotation abilities in MCI under the VR treatment compared to the TAU.

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