# How virtual embodiment affects episodic memory functioning: a proof-of-concept study

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**Abstract.** Recent theories in the field of embodied cognition have pointed out the role of the body for episodic memory, i.e. the memory for personally experienced events. Although virtual embodiment has been used traditionally to investigate the different components of bodily self, it provides great advantages to manipulate the whole embodied experience. In the current study, we manipulated three different levels of virtual embodiment ("full embodiment", "medium embodiment", and "low embodiment"). All participants were asked to navigate in three different virtual cities and memorize all the events that they encountered within each environment. We evaluated the effect of different level of embodiment on the main feature of the recall and recognition (*i.e.,* what events have occurred) and sense of presence. Data emerge with interesting consequences on embodied cognition hypothesis. Accordingly, findings are discussed giving an innovative view of virtual reality as an embodied tool able to influence cognitive processes such as episodic memory.

**Keywords.** Embodiment, Episodic Memory, Embodied Cognition, Virtual Reality

## 1. Introduction

Episodic memory is a neurocognitive system which allows humans to remember personally experienced events (what) in their spatiotemporal context (where and when) along with their perceptual and affective details [1, 2]. One crucial element of episodic memory is binding, the process that connects these features [3]. Episodic retrieval is accompanied by autonoetic consciousness (*i.e.*, the ability of mentally travelling in subjective time in past and future events) assessed by RKG paradigm (Remember, Know and Guess paradigm) [4, 5].

Embodied cognition researchers have been recently drawn the attention to the body as being crucial for cognition [5]. As the mind shapes the body, the body shapes our

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cognitive processes. In particular, embodiment can be defined as the effect of our body on cognition (*e.g.,* memory, language, attention, action) [6]. This effect occurs thanks to a sensorimotor simulation that can be defined as the process that allows the re-enactment of previous perceptual configuration. In particular, sensorimotor details lead to better memory performances due to a better encoding elaboration and useful traces during retrieval [8]. This effect was also shown when interacting within virtual environments by means of input devices [9, 11].

Virtual reality (VR) provides powerful multisensory experiences while interacting in simulated environments and can be conceptualized as an embodied technology [10]. Virtual embodiment can be successfully induced by visuomotor synchronicity that enables to alter self-consciousness [11]. Indeed, Kilteni *et al.* [14] showed that immersive VR is an effective tool in manipulating embodiment (*i.e.*, self-location, body ownership and sense of agency). Moreover, embodiment in a virtual avatar provides a rich interactive experience in simulated environments; this interaction could be exploited to enhance cognition, such as episodic memory [13]. Finally, VR offers standardized trials for studying episodic memory in ecological context similar to real life conditions [8].

The main aim of this study was to study whether different virtual embodiment levels (full, medium and low) have an impact on episodic memory recall and recognition. We expect that full embodiment condition, confirmed by high embodiment scores at the questionnaire, would have high level of presence compared to medium and low condition and that full embodiment leads to better recall and recognition performances compared to medium and low condition.

## 2. Method

### *2.1 Participants and Design*

14 young participants (7 males and 7 females; mean age = 22, SD = 2.08) with no history of psychiatric or neurologic disorders were recruited. The experiment was carried out as a within-group counterbalanced study.

### *2.2 Material*

In the present study three virtual cities were created at the Memory and Cognition laboratory using Unity 3D and in-house software (Editomen and Simulmem). The three cities were built with a single main street with two turns; each city was composed of three virtual blocks of the same size. Along the path buildings and other city elements (*e.g.,* cars, traffic lights, signals) were placed. Each city was composed by five relevant landmarks (*e.g.,* church, green skyscraper, temple, gas station, parking, playground) and five events (*e.g.,* woman asking the time, break-dancers, couple kissing, dog barking, guitarist playing a song). For each city, landmarks and events were unique and placed along the sidewalks in order to have the same amount of events and landmarks per side across the path (*i.e.,* four on the left sidewalk, four on the right sidewalk and two at the end of the road in the middle). Landmarks and events were placed along the path: three of them where placed at the beginning, four in the middle and three at the end. Microsoft Kinect was used to detect knees and arms movements.

Participants watched the navigation with Oculus Rift DK2 from a first-person visual perspective. We connected Kinect V2 for Windows with Oculus Rift DK2 on Windows

8.1 64 Bits, Area 51 Alienware (i7-3.30Ghz; 16Go RAM; GC: Geforce Titan X), which was used to launch the virtual environments and the recognition task.

*2.3 Procedure*

Each participant read and signed the consent form. Then, they were informed that they would have to navigate in three different cities and they were informed that after navigation their memory would be tested. Participants were randomly allocated to the full, medium and low condition and each city was also randomly paired to one of embodiment conditions. For the *full condition* participants saw their avatar in a mirror in a virtual room. In order to induce virtual embodiment, they were asked to stand upright in front of the Kinect and raise slowly each limb at a time five times. Then they were placed in a training virtual city and they were asked to march in place to walk and to touch their forehead with their right or left arm to turn. After they familiarized with the interaction, the virtual task began. In the *medium condition* participants saw the navigation executed by the experimenter by means of keyboard. In the training phase, they were instructed by the experimenter on how to follow a passive navigation in the virtual environment (*i.e.,* "You will see the navigation of someone in the city. Touch your right forehead when you "see" the path turning on the right"; touch your left forehead when you "see" the path turning on the left", "Move your foot on the spot when the path continues"). Finally, in the *low condition* participants were asked to stand upright and watch still the navigation executed by the experimenter with arrow keys. In the last conditions the Kinect was turned off since no embodiment (*i.e.,* no avatar) was provided; participants watched the navigation by means of the head-mounted display. In the medium condition a synchronous walk of a passive navigation was performed, while in the low condition the participant was asked to stay still and simply watch the passive navigation. In each condition, participants were told to memorize all the events that they will encounter within the environment and pay attention to perceptive details such as colors and spatial and temporal contexts (*e.g.,* on the right or left, temporal order). Participants were also asked to pay attention and memorize the buildings, shops, and the other elements present in the city.

After each navigation, participants underwent a distractive task (ten minutes). Neuropsychological tests were administered and short presence questionnaire (feeling of presence) was filled in. The latter was specifically designed for this experiment but based on the one administered by Lessiter *et al*. [14]. Embodiment questionnaire used by Piryankova *et al.* [17] were administered only for the full embodiment condition, since in the other conditions no avatar was provided. The questionnaire investigated location, ownership and agency. We used a short version adapted for the current study. Then, episodic recall was tested with a standard procedure developed by Memory and Cognition Lab [*e.g.,* 10, 18]. Participants were assessed on what (*i.e.,* events and landmarks) on a free recall and recognition task. For the free recall assessment, the experimenter asked the participants to recall the main elements encountered along the navigation (five minutes max.). To each correct response one point was assigned in a grid by the experimenter. Free recall was calculated by summing the points. Therefore the maximum score was ten for each recall session; additional items, which were not considered relevant (*e.g.,* cars, bins), were in any case recorded in the grid. This task was administered after each condition. At the end of the session a computer-based recognition task was carried out. We used the Neuropsydia module for Python [19] to build the task. The computer displayed an element (*e.g.,* an event or a landmark) and the participant had to answer ("Yes" or "No") with the mouse whether he/she saw or did not seethe image in one of the cities. 30 images were presented, 15 were actually in the cities, whereas 15 were distractors; nine of the images were events, six were landmarks for both actual items and distractors. If their answer was "Yes" their recognitions were assessed with the RKG paradigm [20] and both source memory for the city in which they thought had encountered the item and for the embodiment condition. Therefore, they had to indicate if they saw the item in the first, second or third city and if they were in the full, medium or low condition.

## 3. Results

In order to analyze embodiment questionnaire scores for full embodiment and presence questionnaire a paired sample t-test was performed. We performed one-way within-groups ANOVA for each total free recall and recognition scores for total scores and event and landmark sub-scores. Paired t-test was conducted for post-hoc analysis. In the analysis, one subject was excluded due to virtual sickness in the full embodiment condition. Significance level was fixed at $\alpha = .0167$ for Bonferroni correction and at $\alpha = .05$ for t-test.

### *3.1 Embodiment Questionnaire*

The paired sample t-test revealed a significant difference in the scores for ownership (M = 3.59, SD = 0.74) and location (M = 4.54, SD = 1.13), [t(12) = -3.59, p = .004]. A significant difference was found also for ownership scores and agency scores (M = 4.77, SD = 1.42), [t(12) = -3.03, p = .001]. Finally, any difference was found for location and agency scores [t(12) = -3.03, p = .577].

### *3.2 Presence Questionnaire*

Repeated measures ANOVA showed a significance [$F(2,24) = 6.592$, $p = .005$, $\eta_p^2 = .355$] in the presence questionnaire scores. Post hoc comparisons reveled statistically significant results (p = .013) between full embodiment (M = 3.22, SD = 0.43) and low embodiment (M = 2.66, SD = 0.58) and between medium condition (M = 3.18, SD = 0.34) and low condition (p = .010). Finally, no difference was found in the scores between full and medium conditions (p = .801).

### *3.3 Free recall task*

Repeated measures ANOVA did not highlight significant differences for free recalls on scores across the three conditions. Free recalls regardless the type of item (*i.e.*, event or landmark) did not show statically significant results [$F(2,24) = .044$, $p = .957$, $\eta_p^2 = .004$]. Any significance was found for free recall for events [$F(2,24) = .209$, $p = .813$, $\eta_p^2 = .017$] and landmarks [$F(2,24) = .947$, $p = .402$, $\eta_p^2 = .073$]. Last, any significance was found for non-relevant items [$F(2,24) = .888$, $p = .424$, $\eta_p^2 = .064$].

### *3.4 Recognition task*

Repeated measures ANOVA did not show statistically significant differences for correct item recognition across the three conditions [$F(2,24) = .293$, $p = .749$, $\eta_p^2 = .024$]. Again any significance was found for item (what) recognition depending on the type of item, respectively [$F(2,24) = 1$, $p = .383$, $\eta_p^2 = .077$] for events and [$F(2,24) = 1$, $p = .383$, $\eta_p^2 = .077$] for landmarks. Any significance was found for Remember responses [$F(2,24) = .794$, $p = .466$, $\eta_p^2 = .062$], Know responses [$F(2,24) = .409$, $p = .669$, $\eta_p^2 = .033$] and Guess responses across the three conditions regardless the type of item. Finally, source scores (respectively city and city paired with condition) regardless the type of item, did not evidence any statistically significant results [$F(2,24) = 1.531$, $p = .237$, $\eta_p^2 = .113$]. However, interesting trends are reported in Table 1 for what recognition and source memory scores.

**Table 1.** Mean (M) and standard deviation (SD) for item and source recognition evidence a positive effect of the high embodiment condition on recognition memory.

| | **Full embodiment** | **Medium embodiment** | **Low embodiment** |
|---|---|---|---|
| **Item recognition** | M = 3,36, SD = 1.04 | M = 3,08, SD = 1.19 | M = 3,15, SD = .80 |
| **Source city** | M = 3,08, SD = 1.26 | M = 2,31, SD = 1.11 | M = 2,69, SD = .95 |
| **Source city and condition** | M = 3,00, SD = 1.14 | M = 2,23, SD = 1.16 | M = 2,15, SD = 1.28 |

## Discussion/Conclusion

In the present study we aim at investigating the effect of virtual embodiment on episodic memory functioning. Results partially overlap with our hypothesis. First, embodiment questionnaire revealed that location and agency were greater than ownership. When comparing our median scores with median scores for each subscale obtained by Piryankova *et al.* [17] , we observed that only our agency score was higher, however overall scores were similar to the ones reported by Piryankova and co-authors. Interestingly, the feeling of presence in the full embodiment was greater than low condition, confirming how self-location and sense of presence are complementary concepts in constructing spatial representations for the body and the environment [12]. However, medium embodiment also showed higher feeling of presence compared to the low condition. These results highlight how motor control also affects sense of presence without an avatar, conferring a critical role of action-intention comparison. The link between intentions, actions and presence was reported by Triberti and Riva [21] and, indeed, in the medium embodiment condition even though the participants did not have the decisional level on the navigation their pantomimed actions were successfully paired with navigational changes. The sense of presence in immersive virtual context might be more related to self-location and agency rather than ownership. These findings confirm the importance of embodiment for the sense of presence, however the sensorimotor involvement, even if simulated (*i.e.,* medium embodiment), contributes to provide presence within virtual environments. Moreover these results evidence that the methodology used to induce presence was correctly designed.

Concerning the episodic scores no effect of condition was found. However, trends in Table 1 indicate a positive effect of full embodiment on episodic memory. Indeed, source memory reflects recollection and is linked to autonoetic consciousness [20]. Finally, some studies showed that active navigation enhance episodic recall endorsing the embodied cognition theories [*e.g.,* 10, 11, 22]. However, the previous experiments used non-immersive environment and to our knowledge, this is the first study that aims at investigating the effect of embodiment with active interaction on episodic memory.

The main limit of the present experiment is the sample size; it is probable that the number of participants mainly affected the results. Future directions for the current study are to enlarge the sample and extend the analysis to the other episodic features investigated by means of recall and recognition tasks (*e.g.*, where, when, binding).

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