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Real-life memory and spatial navigation in patients with focal epilepsy: Ecological validity of a virtual reality supermarket task

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ABSTRACT

Ecological assessment and training of real-life cognitive functions such as visual–spatial abilities in patients with epilepsy remain challenging. Some studies have applied virtual reality (VR) paradigms, but external validity of VR programs has not sufficiently been proven.

Patients with focal epilepsy (EG, $n = 14$) accomplished an 8-day program in a VR supermarket, which consisted of learning and buying items on a shopping list. Performance of the EG was compared with that of healthy controls (HCG, $n = 19$). A comprehensive neuropsychological examination was administered. Real-life performance was investigated in a real supermarket.

Learning in the VR supermarket was significantly impaired in the EG on different VR measures. Delayed free recall of products did not differ between the EG and the HCG. Virtual reality scores were correlated with neuropsychological measures of visual–spatial cognition, subjective estimates of memory, and performance in the real supermarket.

The data indicate that our VR approach allows for the assessment of real-life visual–spatial memory and cognition in patients with focal epilepsy. The multimodal, active, and complex VR paradigm may particularly enhance visual–spatial cognitive resources.

1. Introduction

In spite of a high proportion of patients with epilepsy displaying cognitive disturbances [1–3], only a moderate statistical relationship can be found between subjective memory complaints and results in standard neuropsychological tests [4–8]. This lack of "objective neuropsychological evidence" for the subjective memory problems may emerge from depressive mood or other behavioral characteristics of patients [8–11]. However, a lack of ecological validity of neuropsychological standard tests also remains a drawback when one tries to disentangle the different influences of the dissociation between subjective memory and objective memory [12–15].

Spatial navigation refers to a higher-order cognitive ability that is of central importance for independent living and independent participation in community life. The concept of spatial navigation includes several cognitive abilities such as route learning, visual imagery, scene recognition, topographical memory, orientation, and executive planning [16–19]. It describes the ability to orientate and navigate oneself in real-life, large scale environments [20]. In spite of its high relevance to patients' everyday life autonomy (see e.g., "Activities and Participation" of the International Classification of Functioning, Disability, and Health; [21]), the ecologically valid assessment of spatial navigation and memory has remained a particular challenge [16,22].

In clinical neuropsychology, a general prevailing issue is the generalization of cognitive performance from laboratory and clinical settings to putatively related everyday situations [7,23,24]. In other words, there is a growing need of ecologically valid methods that may train and predict patients' everyday functioning [25–27], particularly concerning visual–spatial functions [16].

Studies addressing the ecological validity of neuropsychological assessment of patients with epilepsy are scant to date [28]. Bell [29] assessed abilities of patients with temporal lobe epilepsy (TLE) using a route-learning task in an elaborate real-world design. Patients made significantly more errors in this task compared with a healthy control group, which suggests that patients with TLE are impaired in tasks requiring the visual–spatial learning of routes. However, the application of such real-world designs may pose certain challenges [30]. For instance, real-world settings can hardly be controlled experimentally and may be expensive and time-consuming. Recent technical advances in virtual reality (VR) technologies, which may simulate real-life environments, have at least in part permitted the experimentally controlled ecological assessment of spatial orientation and memory [31]. Studies of

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Plancher et al. [32,33] have shown evidence for the feasibility of VR applications for measuring both objective cognitive decline and subjective cognitive decline in elderly healthy individuals. Given the lack of correspondence between standard neuropsychological test scores and subjective complaints of patients with epilepsy (see above), these results suggest that VR approaches might be especially suitable for cognitive assessment in patients with epilepsy.

To date, VR has been applied for neuropsychological diagnosis and rehabilitation in a variety of patient groups (see reviews in [34–36]). A recent study revealed impaired spatial learning in a VR setting in a group of patients with TLE [22]. Patients needed longer movement paths and made more errors finding rewarding tokens hidden in boxes in a VR room. Furthermore, a recent study in patients with TLE showed that successful spatial navigation in a VR task was correlated with volumes of parietal brain regions [37], suggesting a critical role of extratemporal functions for spatial navigation [38,39], even in patients with focal TLE [37]. In the studies of Cánovas et al. [22] and Weniger et al. [37], a relationship between VR performance and real-life cognitive abilities was not explored. However, data on this putative interrelationship between visual–spatial demands of VR scenarios and real-life situations are needed to determine whether a generalization from VR performance to real-life behavior is possible [29]. Likewise, data on spatial navigation have only been reported for patients with TLE but not for patients with extratemporal focal epilepsy. In a recent report, we have shown the feasibility and usability of a novel 360° VR device in combination with a VR supermarket task in a sample of healthy adults and in a small sample of five patients with focal epilepsy [40]. We showed evidence for the technical usability of our new VR device. Moreover, we observed robust learning effects in both groups. Performance between both groups could not directly be compared, as duration of the VR program differed for both groups. Also, we did not analyze the commonalities of our task with real-life demands.

Moreover, VR studies of spatial navigation have not addressed the issue of accelerated long-term forgetting [41,42] in patients with focal epilepsy. Because of accelerated long-term forgetting, patients with TLE might show intact performance when being assessed at standard memory intervals (i.e., 30 to 60 min in a neuropsychological standard testing battery) but demonstrate memory deficits at longer intervals (e.g., 24 h; [13,43,44]). Importantly, accelerated long-term forgetting in patients with epilepsy has also been shown for subjective memory complaints in everyday life [45] and standard tests of autobiographical memory [46]. Virtual reality assessment of spatial memory and route learning may, thus, better tap real-life demands when longer delays of memory recall and learning are applied.

In this study, we aimed at comparing the performance between patients with focal epilepsy and healthy controls in a real-life-like VR shopping task. The task approximates complex everyday visual–spatial cognition of memory and navigation during an 8-day rehabilitation program. The idea behind choosing a shopping task was the relevance of shopping for the patients' autonomous everyday living. Shopping has been included in many different studies as an indicator of everyday cognitive performance in patients with epilepsy [47–51]. In addition, it has frequently been reported that patients with epilepsy complain about memory problems in everyday life [52]. By applying the VR shopping task, we, therefore, aimed at simulating a real-life everyday memory scenario. With respect to the approximation of real-life conditions, our study goes beyond previous studies, which have focused on selective measures of route learning and spatial navigation. Moreover, in contrast to previous studies applying different trials on one day only, we recorded data in the course of several days. We furthermore aimed at investigating putative associations of VR data with standard neuropsychological measures, subjective memory complaints, and shopping performance in a real supermarket. We expected that measures of performance in our VR task (i.e., number of correctly bought products and required time for shopping) would be related to both standard neuropsychological measures in the domains of visual–spatial memory and orientation, subjective memory complaints, and shopping performance in a real-life supermarket task (i.e., number of correctly bought products).

2. Methods

2.1. Participants

Patients with focal epilepsy (experimental group, EG) were recruited in the Mara Hospital, Epilepsy Centre Bethel, Germany and in the vocational training unit, Epilepsy Centre Bethel ("*Berufsbildungswerk Bethel*"), Germany. Inclusion criteria were as follows: diagnosis of focal epilepsy, age ≥ 18 years, at least 14 days of a hospital stay, IQ ≥ 85, and proficiency in the German language. Exclusion criteria were as follows: history of photosensitive epilepsy, claustrophobia, changes of antiepileptic medication during the time of the study's duration (variations in doses of the same antiepileptic drug were not an exclusion criterion), and severe psychiatric comorbidity. The Mara Hospital is a German epilepsy center; the "*Berufsbildungswerk*" is a vocational training institution that specializes in young patients with chronic epilepsy. Recruitment was different in the two institutions. In the Mara Hospital, we consecutively recruited all patients who volunteered to participate according to the inclusion/exclusion criteria. For the patients of the vocational training unit, we conducted a search of the medical archive of all patients of the institution in that given time. Patients who matched the inclusion/exclusion criteria were then contacted and asked for voluntary participation. Two female patients and one male patient were excluded from the study. One female patient had to be excluded because her IQ was below the cutoff score for inclusion; the other female patient had to be excluded as comprehensive diagnostic evaluations during her treatment in the hospital revealed idiopathic generalized epilepsy. One male subject was excluded because of psychiatric comorbidity and three psychotropic drugs in addition to the AED. The EG included 14 patients (8 males and 6 females) with a mean age of 31.29 years ($SD = 9.44$, $Min = 19$, $Max = 51$). A detailed description of patients' demographic and clinical characteristics is given in Table 1.

To compare patients' performance on the VR task with that of a neurologically intact control group, we also included a healthy control group (HCG; $n = 19$, age: $M = 31.21$, $SD = 14.26$, $Min = 19$, $Max = 62$; see Table 1). The HCG accomplished the same two-week VR program as the EG. Healthy participants were recruited via local advertisements in public buildings (e.g., general practitioner's offices,

Table 1
Sample characteristics.

	EG ($n = 14$)	HCG ($n = 19$)	Statistic
Age (years)	31.29 (9.44)	31.21 (14.26)	$p = .986$
Male/female	8 m/6f	4 m/15f	$p = .078$
IQ	100.44 (6.13)	108.84 (6.16)	$p = .001$*
BDI-II score	10.00 (8.52)	5.95 (6.99)	$p = .144$
MAC-Q score	21.46 (4.98)	18.21 (5.19)	$p = .087$
Use of computer[a]	4.07 (2.20)	5.11 (1.73)	$p = .140$
Age at epilepsy onset	18.36 (10.87)	–	
Duration of epilepsy	13.00 (10.92)	–	
SGTC	85.7%	–	
Number of AEDs	1.64 (.75)	–	
Epilepsy syndrome			
Frontal	3 (1 L, 1 R, 1 Bi)	–	
Temporal	8 (4 L, 3 R, 1 Bi)	–	
Central	2 (2 R)	–	
Parietal	1 (1 R)	–	
Cryptogenic	35.7%	–	

EG = patients with focal epilepsy; HCG = healthy control group; IQ = abbreviated version of the "performance testing system"; MAC-Q = Memory Assessment Clinics Questionnaire ($Max = 35$, higher scores represent greater subjective memory complaints); BDI-II = Beck's Depression Inventory II; SGTC = secondary generalized tonic–clonic seizures; AED = antiepileptic drug; L = left; R = right; Bi = bilateral.

* $p \leq .05$.

[a] 0 = "never" to 6 = "several times a day".