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The Virtual Shop: A new immersive virtual reality environment and scenario for the assessment of everyday memory

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HIGHLIGHTS

- To evaluate memory with virtual reality is feasible in younger and older adults.
- The Virtual Shop shows good construct validity.
- The Virtual Shop correlates with memory complaints hence is ecologically valid.

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ABSTRACT

Background: Assessing and predicting memory performance in everyday life is a common assignment for neuropsychologists. However, most traditional neuropsychological tasks are not conceived to capture everyday memory performance.
New method: The Virtual Shop is a fully immersive task developed to assess memory in a more ecological way than traditional neuropsychological assessments. Two studies were undertaken to assess the feasibility of the Virtual Shop and to appraise its ecological and construct validity. In study 1, 20 younger and 19 older adults completed the Virtual Shop task to evaluate its level of difficulty and the way the participants interacted with the VR material. The construct validity was examined with the contrasted-group method, by comparing the performance of younger and older adults. In study 2, 35 individuals with subjective cognitive decline completed the Virtual Shop task. Performance was correlated with an existing questionnaire evaluating everyday memory in order to appraise its ecological validity. To add further support to its construct validity, performance was correlated with traditional episodic memory and executive tasks.
Results: All participants successfully completed the Virtual Shop. The task had an appropriate level of difficulty that helped differentiate younger and older adults, supporting the feasibility and construct validity of the task.
Comparison with existing method(s): The performance on the Virtual Shop was significantly and moderately correlated with the performance on the questionnaire and on the traditional memory and executive tasks.
Conclusions: Results support the feasibility and both the ecological and construct validity of the Virtual Shop.

1. Introduction

Appraising memory difficulties and their impact on everyday life is critical, as a large number of diseases impair memory capacities. However, traditional neuropsychological tasks are designed to obtain the person's best performance in optimal conditions and hence poorly capture everyday memory deficiencies. Real life situations that involve memory are generally more complex than

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traditional memory tasks, as they are most often done under multitasking and distracting conditions or while the person is in movement. Furthermore, traditional tests bear little resemblance to common, everyday memory situations. As a result, the relationship between performance on traditional memory tests (e.g., CVLT or WMS-R scales, etc.) and measures of everyday functioning (e.g., self and informant memory diary, patient and informant memory questionnaire, clinical rating, etc.) are at best moderate (see Chaytor and Schmitter-Edgecombe, 2003, for a review; Goldstein et al., 1992; Johnson, 1994; Kaitaro et al., 1995; Makatura et al., 1999; Sunderland et al., 1983), and sometimes absent (Higginson et al., 2000).

The use of virtual reality (VR) can provide a solution to evaluate memory in ecologically relevant and standardized conditions. VR is a computer-based technology that allows users to interact with a three-dimensional multisensory simulated environment (Saposnik and Levin, 2011). The technology is interesting for cognitive assessment because of its capacity to simulate naturalistic environments (Rizzo et al., 2004) while generating safe experimental conditions that are replicable and that remain entirely under the experimenter's control.

A number of studies support the construct validity of VR protocols, i.e., their ability to measure the intended concept (O'Leary-Kelly and Vokurka, 1998). First, many studies have reported positive correlations between performance on VR tasks and traditional or neuropsychological measures targeting the same cognitive functions (Matheis et al., 2007; Lalonde et al., 2013; Henry et al., 2012; Armstrong et al., 2013; Nolin et al., 2016). Second, it has been shown that several VR tests can differentiate between two groups known to perform at different levels on tasks, such as healthy vs. demented older adults (Allain et al., 2014; Banville et al., 2010; Tarnanas et al., 2013; Rand et al., 2007; Werner et al., 2009; Zygouris et al., 2014; Plancher et al., 2012, Rizzo et al., 1997; Rizzo et al., 2001; Cushman et al., 2008; Tarnanas et al., 2015). Furthermore, several studies have shown that VR assessments have ecological validity, i.e., they are able to predict everyday performance (Franzen and Wilhelm, 1996). This was measured by comparing the performance in VR tasks with the performance in equivalent real life tasks (Waller et al., 2001; Cushman et al., 2008; Allain et al., 2014; Renison et al., 2012; Vallejo et al., 2017) or with self-rated questionnaires of daily functioning (Potvin et al., 2011; Plancher et al., 2010; Tarnanas et al., 2013). For instance, in the spatial domain, high correlations were found between spatial learning measured with a virtual maze and a similar real-world maze (Waller et al., 2001) and between spatial navigation measured with a virtual vs. a real hospital lobby (Cushman et al., 2008). In the executive domain, performance on different tasks associated with the day-to-day running of a virtual library was correlated with performance on real life analogous tasks performed in a real library where participants interacted with real objects (Renison et al., 2012). Similarly, the capacity to prepare a cup of coffee (Allain et al., 2014) or to perform a cooking task (Vallejo et al., 2017) in virtual contexts predicted the capacity to perform similar tasks in a real-world setting.

However, most studies on VR assessments have focused on attention (Rizzo et al., 2001; Nolin et al., 2016), executive functions (Lalonde et al., 2013; Armstrong et al., 2013; Henry et al., 2012; Banville et al., 2010; Cipresso et al., 2014), or spatial learning and navigation (Aguirre and D'Esposito, 1997; Gould et al., 2007; Weniger and Irle, 2008; Weniger et al., 2009; Weniger et al., 2011; Iglói et al., 2009; Moffat et al., 2001; Head and Isom, 2010; Weniger et al., 2010; Siemerkus et al., 2012). There are surprisingly few virtual environments or scenarios that have been validated to assess memory activities, and those that have been have mostly relied on object or associative memory (Sauzéon et al., 2012; Sauzéon et al., 2016a; Sauzéon et al., 2016b; Matheis et al., 2007; Plancher et al., 2010; Plancher et al., 2012; Jebara et al., 2014). There are no or very few VR tests that have been conceived to assess memory in the context of typical activities of daily living such as cooking or shopping. Furthermore, the majority of VR studies interested in memory have not relied on *immersive* virtual reality (IVR). In IVR systems, the user wears a display that produces a fully immersive experience and in which computer-generated stimuli evoke multiple senses (i.e., vision, hearing, etc.) (Biocca and Delaney, 1995). IVR requires a stereoscopic head-mounted display (HDM) that optimizes the immersion of the participants inside the virtual environment by allowing a complete 360° view. This increases the realism of the virtual scene and the user's impression to genuinely take part in the environment, a characteristic, which is referred to as the *sense of presence* (Witmer and Singer, 1998). Currently, most VR memory assessments present their environment on a flat-screen (Weniger and Irle, 2008; Weniger et al., 2009; Weniger et al., 2011; Iglói et al., 2009; Moffat et al., 2001; Head and Isom, 2010; Weniger et al., 2010; Siemerkus et al., 2012; Sauzéon et al., 2012; Sauzéon et al., 2016a; Sauzéon et al., 2016b) or on a semi-circular screen (Plancher et al., 2010; Plancher et al., 2012; Jebara et al., 2014), and are therefore non-immersive. The resemblance with a real-world task is further limited by the use of artificial navigation modes such as game pad devices (Parsons & Rizzo, 2008) or the absence of navigation (Matheis et al., 2007). It has been shown that sense of presence is higher for natural navigation mode, such as real walking, than for virtual walking or navigation via pushing a button (Usoh et al., 1999). To our knowledge, the issues of basic feasibility of IVR coupled with a natural navigation mode such as real walking have never been addressed in the field of cognitive assessment.

Thus, VR technologies have considerable potential to assess memory difficulties in everyday life, beyond that of current neuropsychological measures. However, the realism of the current VR tools should be upgraded with more common day-to-day scenarios and the utilization of IVR and a naturalistic navigation mode. This should support the development of IVR assessments that have a better construct and ecological validity to optimize the prediction of everyday memory performance.

The overall objective of this study was to develop an ecologically-valid VR environment and scenario, designed to measure everyday memory in older adults while addressing the limits described above. This new test, the Virtual Shop, was devised with IVR, using natural navigation mode (i.e., walking) and simulating a meaningful and common day-to-day situation: shopping for common items in a convenience store. The task consists in memorizing a shopping list of common items and then to find and fetch them at a convenience store. The first objective was to determine the feasibility of this new VR task in younger and older individuals (Study 1). The task was expected to show good feasibility that is, younger and older adults were expected to be able to walk in the environment, select objects, and use the remote options to validate and cancel object selections. We anticipated that the VR task would have an appropriate difficulty level, with no floor or ceiling effects in terms of correct selections, and that all participants would complete the VR task in a relatively short period of time. A second objective was to assess its ecological validity by measuring the relationship between performance on the VR task and responses on a questionnaire measuring difficulties related to shopping in older individuals with a memory complaint (Study 2). It was expected that performance on the VR task would correlate with the capacity to perform shopping tasks in real life as measured by the questionnaire. A third objective was to measure construct validity. This was done using the contrasted-group method by assessing the effect of aging on VR memory performance in Study 1 and by measuring the relationship between performance on the VR task and performance on a traditional memory tests and on a test that reflects executive functions and processing speed in Study 2. VR task performance was expected to be sensitive to age differences, i.e., younger adults would perform better than older ones. Furthermore, VR task performance was expected to correlate with performance on a traditional episodic memory task. Since the VR task is complex and involves interference, it was also expected that the Virtual Shop task would correlate, albeit to a lower level, with performance on a traditional measure of executive functions.

2. STUDY 1: feasibility and construct validity with the contrasted-group method

To determine the feasibility of the Virtual Shop, study 1 examined whether participants had appropriate interactions with the interfaces of the IVR system and whether the Virtual Shop task had suitable levels of difficulty. The study also addressed construct validity by contrasting the performance of older and younger adults. Because age is associated with a decline in episodic memory (Park et al., 2002), it was expected that older adults would perform worse than younger adults on the Virtual Shop task.

2.1. Material and method

2.1.1. Participants

Forty-nine participants (20 younger adults and 19 older adults) were recruited through postings, magazines for seniors and the CRIUGM participant registry (*Banque de participants du CRIUGM*). Participants were French-speaking, had normal or corrected-to-normal vision, normal hearing and were cognitively healthy (score $\geq$ 26) according to the Montreal cognitive assessment (MoCA; Nasreddine et al., 2005). Among the younger adults 13 were female and 7 male. They had a mean age of 21.65 years (*SD* = 2.46) and a mean education level of 10.55 years (*SD* = 2.05). The older adults comprised 15 females and 4 males with a mean age of 68 years (*SD* = 5.03) and a mean education level of 9.63 years (*SD* = 3.56). Group comparisons using *t*-tests and chi-square for gender comparison revealed no significant differences on demographic characteristics.

2.1.2. IVR measure of everyday memory: the Virtual Shop

The Virtual Shop (in French; *La boutique virtuelle*) is a virtual convenience store that includes the scenario of a shopping task designed to assess everyday memory. The VE is three dimensional, fully immersive and includes the following interactions: navigation (via natural walking), item selection (via a pointer) and a conversation with a character (via natural talking).

2.1.2.1. Virtual environment. The Virtual Shop (see Fig. 1) was developed in collaboration with the Cliniques et Développement In Virtuo (http://www.cliniqueinvirtuo.com). The environment measures approximately 3.5 × 6.5 m and contains common shop elements. Its configuration comprises two central shelves and three refrigerators. A long countertop is placed in the right superior corner and there is a television behind it, which broadcasts a soccer match. Different characters are present in the environment: a cashier sitting behind the countertop and two customers standing in the right inferior corner of the shop (see Fig. 1). The Virtual Shop is run by the program *Virtools 5* on a Dell Precision T3600 PC with an Inter(R) Xeon (R) CPU ES-1620 0 (3.60 Ghz, 10 Gbytes in RAM) processor and a NVIDIA GeForce GTX 600 Ti graphic card. Three-dimensional visual images are presented using the HMD *nVisor ST50*. The HMD provides a stereoscopic vision via two screens placed in front of the eyes (1280 × 1024 full color with 50° diagonal field-of-view) and sound by stereo headphones. The HMD is connected to a PPT-X system (6° of freedom) motion tracker by *WorldViz* which transmits head position/rotation to a *Shuttle* PC computer in order to provide real-time updating of the VE. It allows the user to rotate his/her head in a 360° view and to walk freely in the VE. A motion tracker is also attached to the participant's right hand. The participant moves his or her hand to position a red circle on the objects they want to select. A wireless remote held in the subject's right hand allows the participant to complete the selection of the item by pressing a button. To avoid errors by accidentally pressing the button, the participant is asked to confirm the selection by pressing a validation button. The virtual store is programmed to fit the dimensions of the experimental room in which the task takes place.

Fig. 1. The Virtual Shop. The image shows a version of the Virtual Shop with the items placed on shelves and hung on the walls. In the background, there is the countertop with the cashier.

2.1.2.2. Virtual objects. Seventy-two objects were created to fill the Virtual Shop as targets or distractors (note that these objects could be used in any other virtual environment). Different variables were controlled, tested and reviewed during their development to ensure the objects are equivalent and unambiguous. We first identified 12 semantic categories from each of which six items were identified (Marchal and Nicolas, 2003). They were all concrete objects commonly found in small shops. Each item was then designed in 3D by a professional digital designer to resemble real products. We then used an adaptive/agile procedure to validate the naming of objects, based on previous studies that have validated a set of pictures (Snodgrass and Vanderwart, 1980; Sirois et al., 2006; Brodeur et al., 2010). Effectively, drawings can be misinterpreted and using unambiguous stimuli is crucial in psychological assessments so as to ensure the limitation of confounding variables (e.g., encoding the object with correct/incorrect semantic information). In a first iteration, younger adults were first asked to name the 72 objects. This was done by presenting the 3D virtual objects in a 2D representation of the drawn object one by one on a 15-inch black screen of a PC computer. Items remained on the screen until a response was produced. Naming was judged as correct if it represented the name previously determined for the concept or was a synonym on the basis of the experimenters' judgment. Eight objects were incorrectly identified (less than 60% of correct naming: leek, celery, nightlight, duster, nails, sponge, fork, secateurs).[1] In the second iteration, drawings that had been incorrectly named were modified. Older adults were then showed the

[1] Three drawings were not used on the first iteration due to technical or 3D designed problems.

improved images one by one on a 15-inch screen of a PC computer and were asked to name them. Twelve objects were incorrectly identified (grape, grapefruit, kiwi, beer, wine, cap, nightlight, pencil sharpener, sponge, secateurs, rake). These objects were modified again and their improved versions were validated liberally by our research team.

2.1.2.3. Scenario of the everyday memory task. Prior to completing the memory VR task, participants were familiarized with the virtual devices using a different version of the convenience store in a condition where they were simply asked to walk in the environment and to select an item that was not used in the memory test. They were then introduced to the episodic memory task. The participant was first positioned in front of the countertop, with the shop shelves behind him/her. The experimenter explained to the participant that s/he would be presented with a list of items to memorize and that s/he would later have to "buy" these same items. The experimenter explained that the cashier of the shop will ask two questions the participant will have to answer and will then be instructed to start shopping. The pictures of 12 items were then presented on the flipping pages of a notepad situated on the countertop. A picture of an object was presented in the center of each page with its name written below to ensure that products were correctly identified. Objects were presented one after the other at a rate of one item every 5 s. When presentation was over, the cashier asked the participant a set of brief questions (e.g., "What is the weather like today?") during 20 s as a way to empty the content of the participant's working memory. The cashier then instructed the participant to walk into the store and fetch the objects that had been shown on the pad ("Thanks, you can now go shopping"). The objects were located on shelves, inside refrigerators, hung on walls, or were placed on the floor. Positions were randomized although they were in their appropriate location (e.g., the milk was placed in the refrigerator). Twelve distractors that belonged to the same semantic category as the target items were placed in similar locations. Ambient verbal noise – a conversation between two customers – was presented dichotically through the HMD during the whole task. This was done to increase the ecological validity of the task by reproducing a task completed under distracting conditions.

The following measures were recorded during completion of the VR task: initiation time (time before the beginning of the task and the selection of the first object), time to complete the task, total number of selected objects (validated and non-validated), number of validated objects, number of correct responses, and number of errors (intrusions and repetitions).

2.2. Results

Table 1 displays the parameter values that were recorded in the Virtual Shop task.

2.2.1. Feasibility

Correct responses ranged from 5 to 12 in younger adults and from 2 to 12 in older adults. Only 4 younger and 2 older adults reached the maximum performance. We found no evidence of a floor or ceiling effect in either group and the task yielded a variability of scores. The number of errors was negligible. In both groups, participants selected more objects than they validated. Younger adults validated 93% (mean score) of their selected objects and older adults 87% of them. The initiation time ranged from 1 to 104 s and the completion time ranged from 210 to 782 s. Finally, it is important to mention that the IVR system was generally well tolerated, with no case of task discontinuation due to cybersickness symptoms (see also Corriveau-Lecavalier et al., 2018).

2.2.2. Validity

Separate independent sample *t*-tests were conducted to test group differences on each of the parameter values recorded in the Virtual Shop. Relative to younger adults, older adults reported less correct responses, [$t(37) = 2.44$, $p < .05$; $d = 0.81$], were slower to initiate their first selection [$t(37) = -2.16$, $p < .05$; $d = 0.65$], and required more time to complete the task [$t(37) = -3.88$, $p < .01$; $d = 1.33$]. The groups did not differ in their number of errors [$t(37) = -0.49$, $p = .63$] and in the ratio selected over validated objects [$t(37) = 1.37$, $p = .18$].

3. STUDY 2: ecological validity and construct validity with correlations between performance on the Virtual Shop, an everyday memory questionnaire and traditional memory tests

One objective was to appraise the ecological validity of the VR memory task by assessing whether performance on the Virtual Shop task was related to memory performance in real-life shopping activities as measured with a self-rated questionnaire. Another goal was to appraise the construct validity of the VR memory task by assessing whether performance in the Virtual Shop task was correlated with memory performance on a traditional memory task. Recall in the Virtual Shop task is not immediate as participants need to navigate in the environment to fetch the objects and as shown in Study 1, completion time ranged from about 5–13 min. Thus, the score was compared with delayed recall. This was assessed in older individuals with subjective cognitive decline (SCD). Persons with SCD perform normally for their age on classical memory tests but express a concern about their everyday memory capacities (Jessen et al., 2014). Thus, this group was likely to produce sufficient variability in their level of complaint to assess the relationship between this score and VR performance. A negative correlation was expected between performance on the VR memory task and the level of complaint regarding shopping and errands as a support for ecological validity. A positive correlation was also expected to be found between the performance on the VR memory task and performance on a traditional measure of episodic memory as a further support for construct validity.

3.1. Material and method

3.1.1. Participants

Thirty-five older adults with SCD were recruited through postings, magazines for seniors and the CRIUGM *Banque de participants*. Participants were French-speaking, had normal or corrected-to-normal vision and normal hearing. Participants were included if they met the Jessen et al. (2014) criteria for SCD group. First, they answered "yes" to the two following questions: "Do you feel like your memory is becoming worse?" and "Does it worry you?" Second, they showed no impairment on objective measures of cognition based on the Story Recall II Part A of the Weschler Memory Scale-III (Wechsler, 1997, Québec French adaptation), the MoCA (Nasreddine et al., 2005) and the Stroop-Victoria test (Troyer et al., 2006; French adaptation from Moroni and Bayard, 2009; Québec French norms from Tremblay et al., 2016. Performance on the Stroop (completion time) was deemed normal when scores were no longer than 1.5 standard deviations away from the mean of age- and education- matched normative samples. Performance on the Story Recall task was considered normal based on education-adjusted cut-off scores used in the ADNI (Alzheimer's Disease Neuroimaging Initiative) study and taken from Bennett et al. (2002) and Petersen et al. (2010). Performance on the MoCA was considered normal if it was equal or higher than the 26 cut-off score, as determined by Nasreddine et al. (2005) (see Table 2). Partici-

Table 1
Performance in the Virtual Shop.

Variable	Younger adults $N = 20$		Older adults $N = 19$	
	Range	Mean (SD)	Range	Mean (SD)
Correct responses (/12)	5–12	9.60 (1.97)*	2–12	7.68 (2.73)
Errors (intrusions + repetitions)	0–1	0.10 (0.31)	0–2	0.16 (0.50)
Selected objects	5–17	10.55 (2.54)	5–18	9.63 (4.19)
Validated objects	5–12	9.70 (1.92)*	4–12	8.00 (2.36)
Initiation time (s)	1–72	24.25 (19.33)*	87–104	38.68 (24.51)
Total time (s)	210–643	312.65 (99.17)*	300–782	487.74 (158.08)

* Significant group difference; $p < .05$.

Table 2
Clinical characterization.

Measure	Score Mean (SD)	Cut-offs for normal score
Stroop Victoria (*Z* score for time)		
First plate	0.13 (0.66)	≤ 1.50
Second plate	0.07 (0.56)	≤ 1.50
Third plate	0.05 (0.66)	≤ 1.50
MoCA (/30)	27.74 (1.65)	≥ 26
Logical Memory IIA, WMS-III (/25)	15.51 (3.57)	8 years of education: > 3 9–16 years of education: > 5 > 16 years of education: > 9

Note: MoCA, Montréal Cognitive Assessment; WMS, Weschler Memory Scale; A negative *Z* score for the Stroop means a better performance score than what is normally expected.

Table 3
Performance on the Virtual shop, subjective memory questionnaire and neuropsychological measures.

Measure	Raw score Mean (SD)
The Virtual Shop	
Correct responses (/12)	7.23 (2.78)
Initiation time (s)	32.66 (30.75)
Total time (s)	479.46 (152.90)
MMQ-Shopping (/8)	4.86 (1.42)
RL/RI-16 delayed free recall (/16)	12.03 (1.77)
Stroop Victoria	
Low interference score	1.29 (0.16)
High interference score	2.17 (0.51)

Note: MMQ-Shopping, a single score which comes from the addition of the two questions related to shopping in the Multifactorial Memory Questionnaire – Memory Ability Scale; RL/RI-16, 16-item Free and Cued Recall.

pants included 29 females and 6 males with a mean age and of 67.20 years ($SD = 7.87$) and a mean education level of 16.06 years ($SD = 3.02$).

3.1.2. Instruments

All participants completed the *Multifactorial Memory Questionnaire* (MMQ – memory ability scale [MMQ-ability], Troyer and Rich, 2002; French version: Fort et al., 2004), which measures memory in everyday life (internal consistency measured by Cronbach's alpha = 0.88). Participants were asked to rate difficulties in performing different daily memory activities on a Likert scale ranging from 1 (*never*) to 5 (*all the time*). Thus, a larger score indicates more frequent difficulties with the activity. Here, we focused on two questions that refer to shopping activities (item 8: *How often do you forget to run an errand?* and item 19: *How often do you forget to buy something you intended to buy?*). The scores of the two questions were added up to obtain a single score (MMQ-shopping). Participants also completed a validated neuropsychological measure of verbal episodic memory (*Épreuve de rappel libre/rappel indicé à 16 items,* RL/RI-16; Van der Linden et al., 2004), which involves word-list learning with immediate and delayed free and cued recall. The delayed free recall was selected for this study, as it is more comparable to the VR retrieval measure than the immediate free recall, given that both have a delay between encoding and recall. The Stroop-Victoria (Troyer et al., 2006; French adaptation from Moroni and Bayard, 2009) was used as a measure of executive functions. In this task, participants must name the stimuli presented on a plate as fast as possible under three conditions: 1) naming the color of the ink of colored dots (dots printed in blue, green, yellow or red); 2) naming the color of the ink of common words printed in the same colors as dots; 3) naming the color of the ink of color words printed in a conflicting color (e.g., the word blue printed in red). Thus, the third condition requires participants to suppress a habitual or automatic response in favor of another. The completion time and number of errors were measured for each condition, but here we only used completion time as a measure of performance because of the lack of variability across participants in the number of errors. Two scores were computed using completion time: 1) Word/Dot (low interference) and 2) Interference/Dot (high interference). Finally, the Virtual Shop task was completed as described above (cf. study 1). The questionnaire and the neuropsychological assessment were completed in a single session prior to the one where they completed the Virtual Shop task.

3.2. Results

Table 3 displays the scores from the Virtual Shop, the MMQ-shopping and the RL/RI-16. A Pearson correlation analysis showed that the number of correct answers in the Virtual Shop was negatively correlated with the MMQ-shopping complaint score ($r = -0.34$, $p < .05$). Thus, lower recall in the Virtual Shop task was associated with reporting more frequent difficulties related to shopping in daily life. The initiation time score of the Virtual Shop was also correlated with the MMQ-shopping complaint score ($r = 0.42$, $p < .05$); participants who took more time to select the first item in the Virtual Shop task also showed a higher MMQ-shopping complaint score. There was no association between time to complete the VR task ($r = -0.06$, $p = .75$) and the MMQ-shopping complaint score. Importantly, performance on the Virtual Shop was not correlated with the global MMQ-ability score ($M = 45.82$, $SD = 12.39$; correlation with correct recalls: $p = .44$) or with the MMQ-ability score that pulled out the 2 shopping items (correlation with correct recalls: $p = .13$). This indicates that the relationship between the RV task and performance in daily life is specific to activities similar to those tested in the Virtual Shop.

The scores for correct recall in the Virtual Shop task were positively correlated with traditional neuropsychological measure of episodic memory ($r = 0.35$, $p < .05$). However, performance on the measure of episodic memory did not correlate with the MMQ-shopping complaint score ($p = .10$), the global MMQ-ability score ($p = .29$) or with the MMQ-ability score when the 2 shopping items were removed ($p = .53$).

Initiation time on the Virtual Shop was positively correlated with completion time for the first ($r = 0.40$, $p < .05$), second ($r = 0.62$, $p < .01$), and third plate ($r = 0.52$, $p < .01$) of the Stroop-Victoria. A similar effect was found for correct recall on the Virtual Shop task, which was negatively correlated with the completion time for the first ($r = -0.52$, $p < .01$), second ($r = -0.49$, $p < .01$), and third plate ($r = -0.53$, $p < .01$) of the Stroop-Victoria. The MMQ-shopping complaint score ($r = 0.59$, $p < .01$) was positively correlated with completion time on the third plate. The low and high interference scores were not correlated with any of the VR scores.

4. Discussion

The Virtual Shop task is a fully immersive VR task designed to assess everyday memory. Our main goal was to assess its feasibility in younger and older adults and to assess its construct validity by contrasting the performance of younger and older adults on the task (cf. study 1) and by correlating VR scores with scores on a traditional measure of episodic memory (cf. study 2). We also wanted to provide preliminary ecological validity data by correlating the performance on the Virtual Shop to memory performance in shopping activities (cf. study 2). Overall, results suggest that the Virtual Shop is an adequate and valid measure of everyday life memory in healthy individuals.

Our first objective was to assess the feasibility of the Virtual Shop task to measure everyday memory in younger and older adults. We examined how the two age groups behaved and performed during the scenario of the Virtual Shop. We were interested in the distribution of scores and completion time and how they interacted with virtual objects. We found that younger and older adults were able to perform the task and that there was neither a floor, nor a ceiling effect, as only a few participants reached the maximal score. We also found that the overall completion time of the VR task was relatively short (less than 15 min for all participants) despite the fact that there was no time limit in the VR task and that the participant could explore the environment freely. This duration is close to the administration time of most episodic memory tests, which is an advantage as time is often limited in clinical or experimental cognitive assessment (Strauss et al., 2006). Importantly, such a relatively short VR exposure time might help to minimize risks of cybersickness that can occur in immersive VR (Jaeger and Mourant, 2001).

We were also interested in the usability of the virtual pointer technique used to interact with the virtual objects, particularly for older adults. Typically, virtual pointer techniques are challenging because one needs to disambiguate the object where the user is pointing (Poupyrev et al., 1998). To avoid this problem, a validation step was added so that the user could cancel a selection when it was not the one they had intended to select. Younger adults cancelled 7% of their selections, whereas older adults cancelled 13% of them, and the difference was not significant between groups. This indicates that both groups used the validation procedure to cancel a selection and that it was appropriate to implement a two-step response strategy (select then validate) in the VR task, regardless of the participant's age. Thus, the procedure is an advantage, as it provides some flexibility for the user to select their response, and participants evidently do use it. The high level of performance in terms of correct answers suggests that object selection was not an obstacle in the success of the task. Nevertheless, some evidence shows that the manipulation of the virtual pointer is more challenging for older adults than for younger adults: the former group cancelled more responses and took more time than younger adults to initiate their first selection. This is consistent with previous findings indicating that mouse and touchscreen control is more difficult for older adults compared to younger adults (Smith et al., 1999; Rogers et al., 2005; Findlater et al., 2013) and should be taken into account when these two groups are compared. Importantly, we found no evidence of difficulties regarding the navigation via real walking. This is important because the task involves a relatively cumbersome/heavy device to project the VR environment. One might have expected older adults to show balance problems or discomfort. However, this was not the case here, all participants fully completed the VR task and there was no incident in relation to the walking activity. The feasibility of walking navigation in VR assessment is therefore supported by our study. Nevertheless, our study highlights a few methodological issues that might be of relevance to those interested in designing a walking VR tasks for older adults. First, the longer completion time of older adults compared to younger ones could reflect not only age-related differences in cognitive performance but also age differences regarding walking speed. Thus, the time variable should be used with caution when comparing the memory performance of different age groups, because it might reflect more than just cognitive process. Furthermore, slower walking might slightly increase the delay between encoding and retrieval in older adults, a variable that might impact performance. On the other hand, walking while shopping is akin to reality. In real life, it is known that older adults have lower gait speed (Lajoie et al., 1996), that gait and cognition are strongly related (Ambrose et al., 2010; Ijmker and Lamoth, 2012; Martin et al., 2013), and that older adults show gait changes when they simultaneously perform an attention-demanding task (Woollacott and Shumway-Cook, 2002; Beauchet et al., 2005). Thus, this is reflected in ecologically valid tasks such as the VR shopping task.

Our results from Study 1 and 2 support the construct validity of the Virtual Shop task. It was first evidenced by the contrasted groups approach of Study 1. In this approach, the mean score of two groups known to be high and low in the construct are compared and should differ significantly in the expected direction if the instrument is valid (Cronbach and Meehl, 1955; DeVon et al., 2007). As expected given appropriate construct validity, older adults showed a smaller number of correct recall and longer completion time than younger adults, which suggests that the VR task is sensitive to the aged-related difference in episodic memory. In addition, Study 2 showed that the performance of participants in the Virtual Shop task was positively correlated with the performance measured on a traditional neuropsychological measure of episodic memory. This suggests that the Virtual Shop task assesses a construct that is similar to the one measured by typical episodic memory tests. Overall, these results are consistent with those obtained in other studies, demonstrating the capacity of virtual assessments to measure specific cognitive functions (Plancher et al., 2008; Plancher et al., 2012; Armstrong et al., 2013; Henry et al., 2012; Parsons and Courtney, 2014; Nolin et al., 2016) and to discriminate between populations (Gould et al., 2007; Tarnanas et al., 2013; Zygouris et al., 2014) including younger vs. older adults (Rand et al., 2007; Plancher et al., 2010; Cushman et al., 2008; Jebara et al., 2014). It is however important to point that though significant, the magnitude of the correlation between the Virtual Shop and the traditional episodic task is relatively weak, suggesting that other cognitive functions are involved in the Virtual Shop tasks.

Interestingly, Study 2 showed that completion time on the three Stroop-Victoria conditions shows a positive correlation with the time to select the first object (initiation time) in the Virtual Shop and a negative correlation with overall performance. We found no correlation between the VR task and interference scores. This suggests that the performance on the Virtual Shop task is linked to processing speed and not to executive function as measured here. The finding of a correlation between performance in the Virtual Shop and speed is not unexpected as episodic memory performance in aging has often been found to be mediated by processing speed (Bryan and Luszcz, 1996; Park et al., 1996; Hertzog et al., 2003). The absence of a contribution from inhibition processes is unexpected since the Virtual Shop task requires that participants inhibit auditory and visual interference. Lack of a correlation might be due to the fact that we are using only one inhibition task, which might not capture all of the processes involved in inhibition. It is also possible that our scenario was not sufficiently demanding on executive functions. Other virtual reality tasks were shown to correlate with executive measures (Raspelli et al., 2012; Cipresso et al., 2014), but those tasks were designed to solicit executive capacities. For instance, the VMET (The Virtual Multiple Errands Test, Raspelli et al., 2012), which involves 4 shopping tasks to be performed while respecting pre-determined rules, was found to highly correlate with performance on tests of divided attention, intermodal comparison, incompatibility and attention shift. Cipresso et al. (2014) also showed that the VMET better detects early executive deficits in Parkinson's disease than traditional executive tasks.

Our findings suggest that the Virtual Shop is related to self-reported everyday performance in shopping, hence supporting its ecological validity. This was done by measuring the correlation between performance in the Virtual Shop and subjective complaint regarding shopping and running errands in persons with SCD. Importantly, the two measures were taken in separate sessions and they are thus unlikely to be influenced by spillover effects. Interestingly, the Virtual Shop was correlated with the MMQ-shopping – a score provided by the two questions related to shopping activities – but not to the global score of the memory questionnaire. This indicates that the memory performance measured in the Virtual Shop reflects the specific everyday memory performance in everyday shopping activities. Hence, it suggests that everyday memory is not a global concept but is highly related to the context of measurement.

Interestingly, we found no correlation between the self-rated MMQ-shopping and performance on the traditional episodic memory task. This is unsurprising because a number of studies have highlighted that traditional measures lack ecological validity (e.g., Higginson et al., 2000). Combined with the data reported above, this suggests that virtual assessment might be more sensitive to the memory complaints of older adults than traditional neuropsychological tests (Plancher et al., 2008, 2010, 2012), and might thus better reflect real-world performance (see Parsons et al., 2015, for a review). However, we found that the effect was quite specific in that the virtual shopping test was related to shopping activities but not to a global measure of memory. It seems that virtual assessments have the potential to measure memory, but that they may capture performance related to the very particular context reproduced by the VR environment and scenario.

These findings should be interpreted in the context of some limitations. First, other functions may be involved in the Virtual Shop task. Motor functions might be particularly relevant, as the VR task requires participants to walk in the environment and select items with a pointing device that requires manual dexterity. We did not include a comprehensive assessment of attentional and executive functions, hence limiting our ability to assess their contribution to the Virtual Shop. Second, our goal was to create a scenario involving a task common in daily life and which requires memory processes. However, the task was not designed to measure fine memory processes and in particular, the capacity to bind an item to its spatial and/or temporal context, a condition which might be closer to contemporary definitions of episodic memory (see Pause et al., 2013, for a discussion of the characteristics that would be required for a task to reflect episodic memory). Other types of VR scenarios might be more amenable to measuring binding processes for instance memorizing items and their locations in a town as was done by Plancher et al. (2010) or retrieving details of different scenarios seen in different rooms such as done by Zlomuzica et al. (2016) and Zlomuzica et al. (2018). Third, the traditional memory test that we used to assess construct validity differs from the Virtual Shop task on a number of dimensions: it relies on *orally presented* material rather than *image-based verbal* material and it provides semantic orientation at encoding. Finally, there are some methodological aspects that were not addressed here in this study such as the test-retest reliability of the Virtual Shop task, the sense of presence or adverse reactions to VR such as symptoms of cybersickness. While the use of IVR might be advantageous, presence of cybersickness symptoms might be seen as a drawback when using the procedure in clinical populations. Very little is known regarding the presence and severity of cybersickness symptoms in clinical populations and it is critical that future studies provide data regarding the tolerability of VR in patients suffering from various health conditions. Yet, it is important to mention that the procedure was well tolerated in the present group of younger and older adults suggesting that those symptoms might not represent a major obstacle to use the procedure in healthy older adults.

5. Conclusion

In summary, the Virtual Shop task is a feasible and valid tool to assess everyday memory in complex conditions that are close to real-life situations in both younger and older adults. Both age groups were able to complete the task within the virtual environment as well as to navigate and select the virtual objects in a reasonable amount of time. Both construct and ecological validity of the Virtual Shop were supported by our data: the task was sensitive to aging, was correlated with a traditional memory task and was related to an everyday measure of shopping abilities. Importantly, we found that the Virtual Shop was better correlated with participants' assessment of their memory ability in real-life than the traditional episodic memory measure. We also found that it was correlated with measures reflecting processing speed. The Virtual Shop task is therefore an interesting tool to reflect memory in an everyday context but other cognitive functions are solicited as well. The Virtual Shop task has great potential to assess performance in persons suffering from very mild memory impairment or in those with SCD who are concerned about their memory but remain unimpaired on traditional tasks. Because the Virtual Shop task is likely reflecting a number of cognitive process including memory and processing speed, it might be more sensitive to a range of very mild cognitive impairment. It has also great potential to measure whether the positive effects of cognitive interventions transfer to real life. Finally, the Virtual Shop or similar virtual reality scenarios have tremendous potential as ecologically validated tools to train cognition in different populations. They might be particularly useful to promote transfer to everyday life for example by allowing participants to practice newly learned strategies in environments that are close to the ones where they will need to apply them. These are approaches that our research team is currently testing.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jneumeth.2018.03.010.

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