Performance within the virtual action planning supermarket (VAP-S): an executive function profile of three different populations suffering from deficits in the central nervous system

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ABSTRACT

Executive functions are those higher-order functions required for performing complex or non-routine tasks. People exhibiting Central Nervous System (CNS) deficits often manifest impaired executive functions, compromising return to full everyday activity and occupation. Such individuals have difficulty performing mundane daily living activities, and especially complex activities – termed Instrumental Activities of Daily Living (IADL). The use of ecologically valid, functional virtual environments constitutes a novel solution to evaluation. The Virtual Action Planning Supermarket (VAP-S) allowed us to compare performance among 3 groups of clients: post-stroke, Minimal Cognitive Impaired, and schizophrenics, and to analyze predictive group membership of the clients (N=83). Results supported study objectives, revealing distinctive performance profiles per group.

1. INTRODUCTION

Executive functions (EF) represent those higher-order functions required to perform complex or non-routine tasks (Godefroy, 2003). Deficits in EF refer to a range of impairments in the sequencing and organization of behavior, and include problems in attention, planning, problem-solving, multitasking, monitoring and behavioral control (Mateer, 1999; Burgess et al, 2000). These deficits may be the consequence of brain damage resulting from traumatic brain injury, stroke or neurodegenerative diseases (Dubois et al, 1991). EF impairments are typically manifested by marked distractibility, difficulties in initiating or suspending activities, exercising mental flexibility, as well as learning novel tasks, despite apparently intact cognitive abilities (Shallice and Burgess, 1991). Individuals with EF impairments evidence handicaps in performing daily living activities, especially those more complex activities, known as Instrumental Activities of Daily Living (IADL) (Chevignard et al, 2000; Fortin et al, 2003). IADL refers to the autonomous conduct of living functions, including preparing meals, managing money, shopping for groceries or personal items, doing light or heavy housework, and using a telephone (National Center for Health Statistics, 2008).

Many tests have been developed to assess different aspects of EF (Godefroy et al, 2004), however, some are limited because they are conducted in artificial situations, engage subjects in stressful and prolonged evaluations, and rely on the self-reporting of cognitive abilities (Odhuba et al, 2005; Chaytor et al, 2006). Problems of ecological validity and biased self-reports are additional concerns, especially among persons with cognitive deficits.

During the past decade, neuropsychological testing has shifted from traditional pencil-paper task tests to computerized assessment tests. The advent of Virtual Reality (VR) promises a range of important benefits for assessment and intervention. VR technology significantly enhances computerized assessments by generating 3D, ecologically-valid stimuli and environments, within which behavioral responses may be objectively measured. Moreover, VR has an additional edge over real-world behavioral observations via the provision of a controlled stimuli environment, where cognitive challenges are presented simultaneously with precise regulation of distractive auditory and/ or visual stimuli (Rizzo and Kim, 2005).

Until recently, the application of VR technology was severely hampered by the lack of inexpensive and user-friendly VR systems. The introduction of newer platforms employing more user-friendly software, has generated an upsurge of potential applications to medicine in general, and rehabilitation in particular. The Virtual Action Planning - Supermarket (VAP-S) (Klinger et al, 2006), was designed for assessing and training individuals to plan a pre-determined purchasing task (Marié et al, 2003). As a VR platform, the VAP-S represents an example of a valid and reliable method to assess EF disabilities in people with deficits in their Central Nervous System (CNS).

The goal of the present study is to compare the respective performance profiles of three populations suffering from CNS deficits resulting from different origins, based upon their distinctive performance on the VAP-S.

2. METHOD

2.1 Participants

Three groups of participants were sampled. The first group included 23 patients after a stroke, with a mean age of 59.1 years (SD 5.5). The second group included 27 patients diagnosed with mild cognitive impairment (MCI), with a mean age of 69.5 years (SD 7.3). A third group included 30 patients diagnosed with schizophrenia and their mean age was 46.7 years (SD 10.6).

2.2 Instrumentation

2.2.1 Task and apparatus. The VAP-S was designed to assess and train the ability to plan and perform the task of purchasing items on a shopping list (Klinger et al, 2004). In fact this original paradigm, similar to the 'test of shopping list' (Martin, 1972), includes a series of actions, described as a task, and allows an analysis of the strategic choices made by participants and thus their capacity to plan.

The VAP-S simulates a fully textured, medium size supermarket with multiple aisles displaying most of the items that can be found in a real supermarket. There are also four cashier check-out counters; a reception point and a shopping cart (see Figure 1). Some obstacles, like packs of bottles or cartons, may hinder the advance of the shopper along the aisles. In addition, virtual humans are included in the supermarket such as a fishmonger, a butcher, check-out cashiers and some customers.

Figure 1. *The original French version of the virtual supermarket (Klinger et al., 2004)*

The test task is to purchase seven items from a clearly marked list of products, to then proceed to the cashier's desk, and to pay for them. Twelve correct actions (e.g., selecting the correct product) are required to completely succeed in the task. Actions are considered as incorrect if the participant: 1) chooses items that are not in the list or chooses the same item twice; 2) chooses a check-out counter without any cashier; 3) leaves the supermarket without purchasing anything or without paying; or 4) stays in the supermarket after the purchases. A training task which is similar, but not identical, to the test is also available to enable the user to get acquainted with the virtual environment and the tools. The task-related instructions are, at first, written on the screen and the target items to purchase are displayed on the right side of the screen. As the participant

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progresses with the purchases, the items appear in the cart and disappear from the screen. The cashier-related instructions are verbal and are given before the beginning of the session.

The participant enters the supermarket behind the cart, as if he is pushing it, and moves around freely by pressing the keyboard arrows. He experiences the environment from a *first person perspective* without any intermediating avatar. The participant is able to select items by pressing the left mouse button. If the item selected is one of the items on the list it will transfer to the cart. At the cashier check-out counter, the participant may place the items on the conveyor belt by pressing the left mouse button with the cursor pointing to the belt. He may also return an item placed on the conveyor belt to the cart. By clicking on the purse icon, the patient may pay and proceed to the supermarket exit.

Two main tools were used to create the VAP-S: 3D Studio Max from Autodesk (www.autodesk.com) and Virtools™ Life Platform from Dassault Systèmes (www.virtools.com). The original VAP-S was adapted by E. Klinger for use by an Israeli population; the names of the aisles and grocery items, as well as all the elements of the task were translated to Hebrew (see Figure 2).

Figure 2. *The Hebrew version of the VAP-S (adapted by Klinger, 2005).*

2.2.2 Outcome measures. The VAP-S records various outcome measures (positions, times, actions) while the participant experiences the virtual environment and executes the task. At least eight variables can be calculated from the recorded data: the total distance in meters traversed by the patient (referred to as the trajectory), the total task time in seconds, the number of items purchased, the number of correct actions, the number of incorrect actions, the number of pauses, the combined duration of pauses in seconds, and the time to pay (i.e., the time between when the cost is displayed on the screen and when the participant clicks on the purse icon).

2.3 Procedure and data analysis

Following a training session dedicated to familiarization with the software and supermarket, participants completed the task without any time limitations. Each subject was assessed in a 20 to 40-minutes individual session either at the hospital, rehabilitation clinic or at home. Data were analyzed by comparing the 3 study groups using a MANCOVA procedure, with the covariate of age due to significant differences between the groups. Further contrasts were conducted to pinpoint specific differences between each of the groups. In addition, a discriminant analysis was performed to examine which of the outcome measures of the VAP-S significantly predicted group membership of the participants.

3. RESULTS

Initial analysis of the data showed that 14 participants with Schizophrenia (47%) were unable to complete the task and omitted the final step (paying at the cashier), therefore in order to perform MANCOVA and discriminant analysis with all participants in that group we omitted the outcome measure "time to pay". Performance results within the VAP-S of the three study groups are presented in table 1. Significant between group differences were obtained for performance in the virtual supermarket based on the MANCOVA test ($F(14,140)= 5.15$, $p= .0001$, ES-$\eta 2= .34$), however no effect for age was found ($F(7,70)= 0.42$, $p= .89$, ES-$\eta 2= .04$). Performance differences were significant for all outcome measures and the contrasts showed significant differences to be evident between all groups. Comparing to the two other groups the MCI group participants were slower performers, making more stops and wrong moves, yet purchasing more items. The stroke group participants, compared to the Schizophrenia group, were slower performers, making more stops and wrong moves, yet purchasing more items. The Schizophrenia group performance had a larger variance than the other two groups in most outcome measures (See Table 1). The discriminant analysis showed that the outcome measures of the VAP-S composed a significant function (Wilks' Lambda= .29; $p<.0001$) and predicted group membership of 71.3% of the participants (kappa=.57; $p<.0001$). Table 2 shows the predicted groups membership of each group; indicating that the prediction was more accurate with the MCI and Stroke groups.

Table 1: *Performance of the three study groups within the VAP-S along with the results of contrasts of the MANCOVA.*

	Stroke (N=23)		Mild Cognitive Impairment (N=27)		Schizophrenia (N=30)		
	Mean	SD	Mean	SD	Mean	SD	Contrasts*
Trajectory	200.71	83.08	309.89	91.74	156.78	106.68	St<MCI MCI>Sch
Total time of performance (min)	10.44	4.05	17.86	3.95	7.21	5.11	St<MCI>Sch St>Sch
Number of items purchased	5.91	1.53	6.93	.27	3.43	2.96	St<MCI>Sch St>Sch
Number of correct actions	10.52	2.59	10.93	2.72	6.73	4.74	St>Sch MCI>Sch
Number of incorrect actions	2.78	3.01	7.52	2.58	1.50	3.05	St>Sch MCI>Sch
Number of pauses	23.91	10.80	38.93	8.77	13.23	8.03	St<MCI>Sch St>Sch
Total duration of pauses (sec)	5.39	3.05	9.58	3.38	3.56	2.58	St<MCI MCI>Sch

* Shows significant differences between the various groups
St=stroke; MCI=Mild Cognitive Impairment; Sch=Schizophrenia

Table 2*: Predicted group membership according to the discriminant analysis*

Original groups	Predicted groups			Total
	Stroke	MCI	Schizophrenia	
Stroke	17	3	3	23
MCI	4	23	0	27
Schizophrenia	12	1	17	30

4. DISCUSSION

Results of this study supported our stated objective. A distinctive performance profile for each group was demonstrated: while the patients with Schizophrenia performed, in general, similarly to the post-stroke patients, significant differences were found between these two groups on five outcome measures (See Table 1). Analysis of MCI patients' performance showed that although their strategies appeared to be less efficient (e.g. made more stops and incorrect actions), they were, nevertheless, able to complete the task (i.e. purchase

more items). People who are diagnosed with MCI are thought to be in a critical transition between normal aging and dementia. The definition of MCI thus needs to be expanded to include clinical heterogeneity, with two recognized subtypes: amnesic - including memory impairment, and non-amnesic - including impairment in other non-memory cognitive domains. Primary non-amnesic deficits incorporate limitations in executive functioning (EF) (Winblad et al, 2004). The complex picture of overall task success, albeit with less efficient strategies, may reflect this transition. These results emphasize the advantage of the VAP-S outcome measures which provide information about the process of performing a task and not only the end result. Performance of the patients with Schizophrenia suggests that they have deficits in executive functions, which was reported in the literature (Katz et al, 2007). They performed the task rapidly and made fewer pauses, however they committed more errors, failed to purchase their needed items and did not approach the cashier to pay - the final step of the task. Finally, it seems that when looking at all the outcome measures, the patients with stroke performed the task better then the other groups.

The results of the discriminant analysis showed that the VAP-S measures provide an effective way to differentiate among the three respective groups: more than 70% of the participants were correctly categorized according to their group and initial diagnosis. The categorization was more accurate in the MCI and stroke groups than in the Schizophrenia group which also showed a larger variance in their performance. This promising finding may enable clinicians to utilize a brief test and user-friendly environment in order to provide a valid report about patients' EF and their respective diagnoses.

5. CONCLUSION

In the future, this environment could enable evaluation and prediction of patient performance, in relation to other components of executive functioning, such as inhibition and sequence. The relatively low cost of this virtual environment makes it an attractive and feasible option for wider utilization and implementation in rehabilitation clinics. Future studies will aim to develop a more comprehensive outcome measure to the task as well as use this environment as a training tool with various populations. Furthermore, the VAP-S will be examined in a direct comparison with a real supermarket shopping task, with the objective of revealing the relationship between a virtual environment and real life activities.

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