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Effectiveness of executive functions training within a virtual supermarket for adults with Traumatic Brain Injury

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***Abstract*—Impairments of executive functions (EF) significantly affect the ability to lead an independent lifestyle. Virtual environments (VEs) offer a way to rehabilitate EF due to their ecological validity. The purpose of this study was to examine the effectiveness of a virtual supermarket (VMall) for treatment of EF in patients with TBI, compared to conventional occupational therapy (OT). Twelve men and women, aged 19-55 years, who had TBI resulting in EF impairments participated in this randomized control trial. Outcome measures were the Multiple Errands Test - Simplified Version (MET-SV) and the Executive Function Performance Test (EFPT). Experimental group participants received 10 treatment 45-min sessions in the VMall, and control group participants received 10 cognitive therapy sessions without VR. Treatment in both groups was based on the cognitive retraining model. Baseline performance prior to intervention showed no statistically significant between group differences. Most of the participants improved their performance on the outcome measures after therapy. The VR group demonstrated more improvement than the control group; for some measures the improvement was statistically significant - % relative change of the MET-SV total score (z=-1.76; p=.046) and EFPT total score (z=-1.76; p=.047). The results suggest an advantage to VR therapy compared to cognitive retraining OT without VR, as it leads to greater improvement in the performance of complex everyday activities.**

Keywords-Executive functions; Traumatic Brain Injury; Virtual einvironment; Randomized controlled trial

I. INTRODUCTION

Traumatic Brain Injury (TBI) is one of the main causes of mortality and physical and cognitive disability worldwide [1, 2]. TBI frequently results in deficits in higher level cognitive functions (executive functions (EF) that control and guide lower level body functions [3]. Since EF are necessary for the planning and efficient performance of all purposeful behavior [4], their impairment often leads to an inability to perform activities of daily living (ADL) [5] and especially the more complex Instrumental Activities of Daily Living (IADL) [6]. In order to live independently in the community, a person must be able to cope with and perform IADL, including management of a budget, use of public transportation and shopping. Moreover, the ability to perform IADL was found to be related to a person's quality of life and feelings of personal wellbeing [7]. Thus EF impairments, more than any other cognitive disability, can have significant repercussions on a person's daily function, and even determine the degree to which a person reintegrates into the community [4, 8].

The purpose of occupational therapy is to help individuals improve their level of occupational performance and participation within their community [6] A major challenge is to identify effective and efficient intervention methods that will enable the transfer of strategies and skills gained during therapy to daily life functioning [9, 10]. Cicerone et al. [11] reviewed a wide range of studies that examined the effectiveness of therapeutic intervention of EF impairments in persons affected by TBI. They recommended treatment through problem solving strategies related to exposure to everyday situations and functional activities. Gordon et al. [4] also found that in order to increase independent participation in the home and community, clients should be taught to plan and perform activities in the community. The most effective treatment is based on two principles, namely the learning of general meta-cognitive strategies that can be

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applied in a variety of contexts and the provision of opportunities to cope and apply those strategies with functional problems in real-life situations. Cromby et al. [12] highlighted the difficulty of performing treatment in the community since such interventions tend to be lengthy, expensive and may expose the client to dangerous situations. Treatment in virtual environments may be a solution to this problem.

Virtual reality (VR) refers to an interactive simulation that gives the user an opportunity to perform in an environment similar to a physical environment. The unique advantages of VR include the opportunity for experiential and active learning during an activity that is motivating, the ability to control the amount of stimuli and degree of task difficulty and the ability to objectively measure a client's behavior and performance. In addition, it may be adapted to a client's specific treatment objectives, to provide repetitive exercise and to gradually increase the difficulty of the task, while decreasing the support and guidance given by a therapist [13-16]. VR has been shown to be an appropriate tool for the assessment and treatment of motor skills and cognitive deficits, including EF [17-21].

Since the ultimate goal of rehabilitation is to improve participation of daily activities in the real world, it is important to demonstrate that skills gained in a VR setting transfer to daily real-life situations. There is increasing evidence that VR treatment transfers to real world situations [22, 21]. For example, there are studies that examined how safe street-crossing was learned among children [23] and adults following stroke, who suffer from unilateral neglect [24]. In these two studies, it was found that the subjects who practiced street-crossing through VR showed an improvement in their ability to cross a street safely in the real world. Moreover, post-stroke participants who underwent treatment in a virtual environment of a mass transit railway showed improved knowledge, skill and efficiency in using the mass transit railway [25]. Rand et al. [19] reported substantial improvements in the Multiple Errands Test-Hospital Version – MET-HV [26] in 4 post-stroke participants who received 9 treatment sessions in the Virtual Mall (VMall) in a single-subject design. Yip and Man [27] provided a series of 10 treatment sessions in environments that simulated the use of public transportation and supermarket shopping to three post-stroke participants and one participant following TBI. The environments were developed to enable the practice of life skills needed for community living. All the participants demonstrated improvement in their ability to acquire memory skills and functions, and three of them were able to transfer these skills to a real-world environment.

To date, the emphasis has been on the assessment of EF deficits through the use of VR rather than their treatment [17, 19]. A need exists to further demonstrate the transfer and generalization of treatment in a virtual environment to the real world especially as compared to non-VR cognitive retraining treatment. The goal of the current study was to examine the efficacy of EF treatment through the use of a virtual supermarket, the VMall [28] in comparison with cognitive treatment in occupational therapy without VR. Both treatments were based on the cognitive retraining model [9] as well as the principles suggested by Sohlberg and Mateer [8] for patients with TBI who suffer from EF deficits. An additional goal was to determine whether treatment in the virtual environment influenced function in a real supermarket, and the ability to perform additional everyday tasks.

II. METHODS

A. Population

Twelve people (8 males and 4 females), aged 19-55 years, who had sustained a TBI and had been hospitalized in the Dept. of Brain Injury Rehabilitation at the Loewenstein Hospital participated in the study. Their cognitive function, as determined by the Neurobehavioral Cognitive Status Examination - Cognistat [29] was within normal range. They had EF impairments, as determined by the Behavioral Assessment of the Dysexecutive Syndrome – BADS) [30] without aphasia, unilateral neglect, depression or anxiety. The participants were randomly divided into experimental and control groups. No significant differences were found between the groups in demographic variables such as age, years of education, Glasgow Coma Scale, period of loss of consciousness and time since injury.

B. Instruments to measure outcomes

1) Multiple Errands Test - Simplified Version (MET-SV) [1, 6]

The MET-SV is an assessment designed to examine EFs in a real mall environment. The participant is asked to perform three types of tasks in a shopping center. These include the purchase of six items, obtaining four pieces of information and recording them and meeting with the examiner at a preset location and time while abiding by certain rules. The examiner observes the participant's behavior and records his strategies and mistakes. The test was validated on a variety of populations [31, 32] and has been shown to discriminate between patients with TBI and healthy controls and has been found to have ecological validity [33].

An adapted version of the assessment was formulated for the current study in which a number of changes were made to the MET-SV so that it could be administered in a supermarket, similar to Rand et al. [19] adaptations and scoring referred to as the VMET. The adapted assessment included changes in some of the items to be purchased, in some of the pieces of information to be obtained and in some of the rules. Its content validity was established by five occupational therapists, who were familiar with the MET-SV. One hundred percentof agreement was achieved with respect to the changes made. The scoring included the number of incomplete tasks, mistakes of inefficiency, rule breaking and use of strategies. The final score of performance in the MET-SV was determined by the total number of mistakes made by the participant; the lower the score, the better the performance was.

2) Executive Function Performance Test (EFPT) [34, 35].
This is a standardized assessment which examines EF during the performance of four daily tasks; simple cooking, telephone use, medication management and bill payment. The type and degree of mediation needed to perform the task is recorded for each of the following EF components: initiation, organization, sequencing, judgment and safety and task completion, according to the following scale: 0- independent performance, 1- indirect verbal guidance, 2- gestural guidance, 3- direct verbal assistance, 4- physical assistance, 5- task was performed for the subject. The total score represents the sum of the scores achieved in performing all four tasks. The lower the test scores are, the -more independent was the participant. The test has been shown to be valid and reliable for psychiatric patients [36] and to have discriminant validity for post-stroke population. Internal validity was found to be high (α=.94), as well as inter-rater reliability (ICC= .91) [35].

C. Instruments to Provide Intervention

Virtual Mall (Vmall) [28, 37]. This is a virtual environment of a supermarket which was developed in order to enable training of motor, cognitive and EF abilities during the practice of IADL tasks for people with neurological injury. The environment simulates a large supermarket, which enables the performance of a variety of tasks during a theraputic session. The environment is operated via GestureTek's GX Video-Capture system, which was found to be suitable for rehabilitation of people with neurological deficits [17, 38, 37]. Users see their image on a screen, as in a mirror, and interact within the VE using their body movements [38]. The VMall was examined as an assessment tool and was found to significantly distinguish between post stroke patients and healthy controls [37, 18]. Moreover, a significant correlation was found between performance of the MET-HV (the hospital version of the MET-SV) and the VMET a virtual task based on the MET-HV test, among post-stroke participants, as well as among healthy adults [37, 18-19]. For treatment purpose a variety of tasks can be performed that are graded according to difficulty, in order to treat cognitive and EF impairments such as planning, problem solving and dealing with a multitask situation. After treatment completion, it is recommended to go to a real supermarket in order to ensure that the skills are transferred to a real situation [37].

D. Intervention

The occupational therapy intervention administered to all the participants in the study was based on the cognitive retraining model [9] and the principles for treating EF deficits, as reported by Sohlberg and Mateer [8]:

- Planning tasks - improving the ability to formulate and organize the steps necessary to perform a task, in the proper sequence.
- Task performance – improving initiation and ability to perform a task according to what was planned.
- Time management – modifying behavior according to time constraints. Improving the ability to estimate times, especially while performing a task.
- Monitoring performance – improving the ability to judge performance, to enable the identification of mistakes and self-regulation.
- Meta-cognitive strategies – verbal self-direction strategies and self-regulation to improve impairments in planning, problem solving and impulsivity.

The control group: the participants received cognitive retraining treatment based on the principles mentioned above, according to their level of performance. This is standard treatment administered to patients at the Loewenstein Rehabilitation Hospital. The instruments used were generally didactic and chosen for each participant individually.

The experimental group: for the purpose of the current study, a protocol was developed for treatment via the VMall, as the basis of intervention with the experimental group. The protocol was developed according to the principles of treatment of EF (described above), during which time the participant coped with tasks that require planning, organization, problem solving, multitasking, etc. The level of task complexity was adapted to the needs and abilities of each participant and the level of difficulty was increased according to his/her rate of progress.

E. Protocol

The study protocol included a number of stages:

1. Pre-intervention assessment: The MET-SV was administered in a supermarket close to the hospital and the EFPT was administered in the "Treatment Kitchen" in Beit Loewenstein under quiet conditions.

2. Intervention stage: All participants in the experimental group received 10, 45-min treatment sessions, 3-4 times a week via the VMall environment. The participants did not receive additional occupational therapy intervention during this period. The control group received cognitive retraining treatment as described above. The amount and duration of the treatment sessions were identical to those of the experimental group.

3. Post intervention assessment: The MET-SV (different version) and the EFPT were administered under the same conditions as the pre-intervention assessments.

All the assessments were administered by an occupational therapist who was blind to the participant's allocation to groups and who did not carry out the intervention.

E. Data Analysis

The Statistical Package for the Social Sciences Software (SPSS), version 17, was used to analyze the data, at a significance level of 0.05. Given the small sample size, the variables did not follow a normal distribution, thus nonparametric tests were chosen to

analyze the study data. In order to examine the differences between the experimental group and the control group in their performance on the MET-SV and the EFPT before and after the intervention, the Mann-Whitney test for independent samples was used. Moreover, the percentage of relative change of each participant following the intervention was calculated relative to his/her baseline performance, as follows: the pre-intervention score minus the post-intervention score, divided by the pre-intervention score. The resulting score was multiplied by 100 and, reported as a percentage. The relative percentage of change found in the experimental group was compared to that of the control group, and was also analyzed via the Mann-Whitney test for independent samples. In order to determine the differences between performance in the MET-SV and the EFPT assessments before, and after, the intervention, within each group, the Wilcoxon test for dependent samples was used.

III. Results

A. MET-SV

The pre (grey bars) and post (red bars) MET-SV scores for the participants in the VMall and Cognitive retraining groups are shown in Fig. 1. Decreases in the scores for most participants indicates an improvement in EF following intervention. The first study hypothesis was that a significant improvement would be found in the performance of the MET-SV among the entire study population after having received intervention for EF deficits with the improvement in the experimental group being higher than that in the control group. This hypothesis was partially confirmed; according to the Mann-Whitney test no significant differences were found between the groups in all outcomes of the MET-SV before intervention.

Both groups showed improvements in most of the mean scores of the test measures, post-intervention. Even though the VR group showed more improvement on all test measures, the only statistical significant finding was in the mean percentage of relative change where the participants in the experimental group improved significantly more in their final scores on the MET-SV relative to their initial scores (M=46.21%, SD=37.06), compared to the control group (M=13.52%, SD=19.93) (Z = -1.761, p =.046).

B. EFPT

The second study hypothesis was that a significant improvement would be found in the post-intervention EFPT performance among the entire study population; however the improvement in the experimental group would be higher than that of the control group. This hypothesis was partially confirmed. First, according to Mann-Whitney test significant difference before intervention was found between the groups only in one outcome measure of the EFPT (the organization of performance -Z = -2.445, p =.015), in favor of the control group.

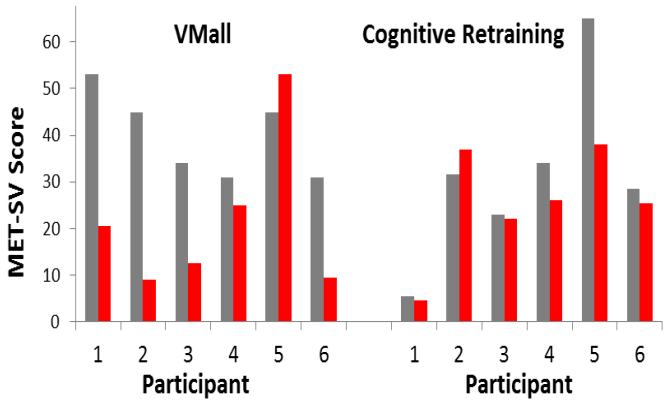

Fig. 1: Pre (grey bars) and post (red bars) MET-SV scores for the participants in the VMall and Cognitive retraining groups.

Both groups improved with respect to the mean final scores on this assessment, as well as in the mean scores of the EF components. Moreover, the mean performance in all the tasks in both groups improved, except for the taking medication task in which the control group performed less well during the second administration.

According to the Mann-Whitney test, participants in the experimental group had a significantly higher mean percentage of relative change in their final scores of the EFPT relative to their initial scores (M=35.5%, SD=19.63), compared to the non-VR cognitive retraining group (M=16.44%, SD=16.77) (Z = -1.761, p =.046).

In addition, the experimental group achieved a significantly better score in the performance organization component, both in the mean score from the post-intervention assessment (Z= -1.813, p=.047), as well as in the measure of relative change (Z= -2.892, p=.001). With respect to the findings on task performance, statistically significant differences were found in the measure of relative change of the taking medications task score (Z = -2.019, p =.021) and in the score for the paying bills task (Z= -2.082, p=.021). In both cases the experimental group improved more than the control group.

IV. Discussion

The goal of this study was to compare the effectiveness of two types of treatment for EF impairments due to TBI; a VR-based treatment using the VMall, a virtual supermarket environment, and non-VR cognitive retraining in occupational therapy. In addition, we examined whether transfer occured from the VR treatment in the virtual supermarket environment to function in a real supermarket environment. To accomplish this, a version of the MET-SV was formulated to assess EF in a supermarket shopping task. We then examined whether transfer occurred from the VMall treatment to the performance of other everyday

instrumental tasks. To accomplish this, the EFPT was selected to assess EF while performing four tasks (such as simple cooking and using medications). Both assessments are scored with respect to task performance, as well as to EF performance components.

The current study is one of the first RCT studies to examine treatment for EF impairments through the use of VR. According to the information that Holm [39] presented regarding the five-level hierarchy of evidence for selecting a method of evidence-based treatment, the current study answers the criteria of the second level, except for the fact that a small sample size and only two study groups were used (i.e., there was not a non-treatment group.

All the study participants, except for two improved their final scores on the MET-SV following the occupational therapy treatment they received with or without VR. With respect to the difference between the types of therapeutic methods used, the study findings indicated that the improvement by the experimental group was greater than the improvement by the participants in the control group, in all outcome measures. From a statistical perspective, the measure of percentage of relative change of the final score on the MET-SV among the experimental group participants was higher in comparison to the control group. These findings lead to two conclusions. First, it is important, and even advantageous to treat EF in daily function context. This conclusion is compatible with that of Cicerone et al. [11] who conducted a broad review of studies to examine the efficacy of therapeutic intervention for EF impairments among individuals with TBI, and found that the most effective treatment incorporated functional activities related to daily situations. Second, transfer occurred from the virtual environment to a real-world environment in the current study. In other words, treatment through the use of the virtual supermarket environment served, in large measure, as an alternative to training in a real supermarket. According to Toglia's terminology [10] regarding the sequence of degrees of transference of cognitive strategies taught in the clinic, to daily situations, it seems that "far" transfer occurred since shopping in a virtual supermarket is an activity with different physical characteristics than the original activity (shopping in a real supermarket). In Crombly et al.'s [12] study transfer was also found to occur from a virtual supermarket to a real supermarket in a population with Intellectual and Developmental Deficits.

With respect to the EFPT in comparing between the groups in the post-intervention study measures, and in the relative change measure, it was found that both groups improved in their mean final scores on the EFPT, and that the participants in the experimental group improved their scores in a statistically significant manner relative to the control group participants on the relative change of the final score of the test in addition to a few of the test measures.

Therefore, it can be concluded that the occupational therapy treatment administered in this study resulted in improved ability to perform daily tasks, as Katz and Hartman-Maeir [6] and McDonald et al. [40] have shown. Moreover, transfer occurred from treatment via VR to additional everyday tasks, such as cooking, taking medications and bookkeeping. This transfer is considered to be "very far" transfer according to Toglia's [10] sequence since these activities are very different, and included the transfer of strategies that were learned in the virtual supermarket environment to the performance of entirely different everyday tasks. It is interesting to note that the mother of one of the participants in the experimental group reported that about two weeks after the completion of the treatment, she saw an improvement in her son's organizational ability in different tasks that he does on the weekends, such as in organizing before leaving the house, organizing his bag for a week of hospitalization, and so forth.

There are a few limitations to the study. First, the study sample was very small and the participants' levels of function were very different, therefore for some of the findings it is difficult to make unequivocal conclusions. It is important to continue, and to add participants to the sample collected thus far. Second, the time since injury wasn't sufficiently homogenous, despite the fact that most of the patients were in the sub-acute stage, 3-4 months post injury. The range fluctuated between two months and almost ten months, and it is possible that this may have influenced the findings. Third, in light of the importance of the level of awareness on executive function, future studies should integrate an assessment of the participants' awareness regarding their functional condition and examine the influence of awareness on treatment efficacy.

V. Summary and Conclusions

A key goal of occupational therapy is to enable clients to achieve maximal participation in everyday life activities. This participation includes, among other things, the ability to perform IADL activities, which have been shown to contribute to the quality of life and to the feeling of general well-being of persons with disabilities. Thus, during the rehabilitative process of people with brain injuries, the therapist must examine the types of existing treatments, and choose the most effective treatment for his/her patients, in accordance with the treatment goals that were set up together with him/her.

As a result of the two types of treatment chosen in the current study, treatment via VR and non-VR treatment both according to the cognitive retraining model, an improvement in the participants' function in the performance of IADL activities was found. Therefore, the main conclusion of the current study is that cognitive treatment in occupational therapy that focuses on mediating strategies to improve executive functions, leads to an improvement in the ability to perform IADL activities among people following TBI. Thus, the two types of treatment are appropriate and it is important to integrate these treatments at appropriate points of times during the course of the rehabilitation period.

In the current study, most of the assessment scores that comprised the outcome measures indicate that treatment through the use of the virtual treatment environment, the VMall, was

found to be more effective than non-VR treatment in occupational therapy. Moreover, it was found that the study participants were able to transfer from the virtual reality treatment to function in the real world, both in similar activities (shopping in the supermarket) and in the performance of additional IADL activities. This study provides an important contribution, since it is one of the first studies conducted according to an RCT format, which provides evidence as to the degree of transfer of the treatment principles from a virtual environment to a real environment.

In summary, this study demonstrates that the VMall is an ecological treatment environment, which provides the occupational therapist with the opportunity to treat impaired executive functions in patients after TBI, in a manner that is enjoyable, economical, safe and effective. In addition, it was shown that strategies used to improve executive functions that are mediated during the course of treatment through the VMall can be transferred and applied to the performance of IADL activities in real-world situations, and therefore are likely to result in functional improvement among patients with TBI. However, it is important to note that this is a first study, with a small sample size, and it is necessary to expand the sample size in order to better establish the conclusions.

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