Designing an ecological virtual task in the context of executive functions: a preliminary study

X Cao[1], A-S Douguet[2], P Fuchs[3], E Klinger[4]

[1,4]Arts et Métiers Paristech - LAMPA, Angers-Laval, FRANCE

[2]Kerpape Rehabilitation Center, Ploemeur, FRANCE

[3]MINES ParisTech, Paris, FRANCE

[1]*cao.elhit@orange.fr*, [2]*asdouguet@kerpape.mutualite56.fr*, [3]*philippe.fuchs@ensmp.fr*, [4]*evelyne.klinger@ensam.eu*

ABSTRACT

Brain damage is a major cause of disability that often leads to deficits in executive functions with dramatic consequences on activities of daily living. While rehabilitation approaches of the dysexecutive syndrome are still limited, virtual reality has shown its potential to propose innovative intervention strategies based on ecologically valid functional tasks. The Therapeutic Virtual Kitchen (TVK) was designed as an assessment tool to help therapists and their patients with brain injury. In the TVK, some ecological virtual tasks may be configured by the therapists for patients' assessment and rehabilitation. The purpose of this paper is to validate the feasibility of the TVK with healthy subjects and patients with brain injury in Kerpape Rehabilitation Center.

1. INTRODUCTION

Executive functions (EF) are defined as higher-order functions that are needed to perform organized goal directed behaviors. EF include the capacity for initiative, formulating goals, planning, organization, reasoning, control, audit, abstract thinking and self-awareness (Godefroy, 2003). Deficits in EF may be the consequence of brain damage such as stroke or Traumatic Brain Injury (TBI). EF alteration, also called the dysexecutive syndrome, disrupts Instrumental Activities of Daily Living (IADL) (e.g. meal preparation), prevents return to social and professional life, and finally leads to loss of autonomy (Fortin et al, 2003). According to literature (Katz and Hartman-Maeir, 2005; Pradat-Diehl et al, 2006), it is recommended to use IADL to assess and train EF. But due to both time and economic constraints, therapists do not have enough opportunities to propose such ecological approaches to their patients. Functional virtual environments seem to be a possible way to overcome these limitations. During the last decade, a wide range of studies has shown the feasibility of using Virtual Reality (VR) for cognitive care (Rizzo et al, 2004; Rose et al, 2005; Klinger et al, 2006). VR has been implemented for assessing and training various cognitive deficits in: Memory (Brooks et al, 2004), Attention (Rizzo et al, 2006) and executive functions (Klinger et al, 2006). In particular, researchers have investigated the potential of virtual kitchens to assess and train patients with dysexecutive syndrome. Davies et al. described the issues encountered in the development of a rehabilitation VR based kitchen work, e. g. the means of interaction with the 3D objects or the way to provide helpful cues (Davies et al, 2002). Zhang et al. proposed to patients after TBI to complete meal preparation both in a VR kitchen and a real kitchen twice over a 3-week period (Zhang et al, 2003). They established the adequate reliability and validity of the VR system as an assessment method in persons after TBI. In their single case study, Fidopiastis et al. trained a participant with working memory impairment in breakfast preparation in a mixed reality. The system included real and virtual objects as well as environmental conditions (Fidopiastis et al, 2006). They underline transfer of learning from the mixed reality environment to the home environment.

In the framework of our collaboration with Kerpape Rehabilitation Center, we designed the Therapeutic Virtual Kitchen (TVK) in which we implemented an adaptable virtual Instrumental Activity of Daily Living (vIADL) (Klinger et al, 2009). The TVK allows the therapist to adapt virtual kitchen tasks to patient capacities, and allows the patient to experience graduated tasks. The goal of this study is to validate the feasibility of the TVK with healthy subjects and patients with brain injury (stroke or TBI). The final purpose of our current work is to investigate how capacities learned in a virtual task can be generalized to the same task in the real world.

©2010 ICDVRAT; ISBN 978 07049 15022

2. INSTRUMENTATION

2.1 The TVK

After having studied the habits and needs of Kerpape therapists, we designed the TVK that is graphically very close to the Kerpape Center kitchen (Klinger et al, 2009) (Figure 1). Its various functionalities include behaviors of all the 3D objects that are required in meal preparation or follow-up of all the activity of the participant. Real sounds are provided according to the activated 3D objects, in order to increase the feeling of immersion within the virtual kitchen. According to the configuration of the task, therapist can provide help to the participant via visual or auditory cues by pressing keyboard keys (F1: a voice, F2: a message on screen, F3: a red arrow to indicate the object to interact with). Mouse visual cues are provided to facilitate the understanding of the interaction opportunities, like the modification of the mouse cursor according to user action (take, pour, activate, connect) (Figure 2). To carry an item from one place to another one, the item is sticked on the mouse after its selection. In our objective of low cost devices use, the virtual task is displayed on a computer screen while the participants navigate and interact with the 3D objects using respectively the keyboard arrows and the mouse while performing the task. The TVK offers the therapist various possibilities to individualize the task, to adapt it to the capacities of the participant (e.g., number of cups of coffee to prepare), to graduate the difficulty by changing the initial position of the required items or to reach therapeutic purposes (assessment or rehabilitation).

Three softwares were used to create the TVK: 1) The *Java* platform for creating the therapist's interface; 2) *Autodesk 3DS Max* (*www.autodesk.com*) for modeling the 3D kitchen; 3) *3DVIA Virtools* (*www.3ds.com/products/3dvia/3dvia-virtools)* for creating the scenario and the tasks in the virtual kitchen.

Figure 1. *Kerpape real kitchen (left) and the TVK (right).*

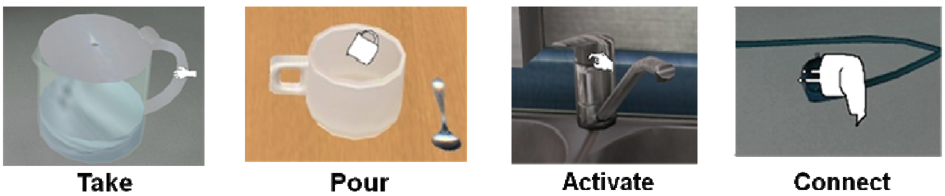

Figure 2. *Four mouse visual cues*

2.2 Virtual Activities of Daily Living (vADL)

The final purpose of the TVK is to engage participants in various vADL, like the preparation of a coffee, a soup or a meal. In order to reach that purpose the TVK software proposes two types of tasks: "primary" tasks and "complex" tasks. Primary tasks (PT) were designed to insure the familiarization of the participant to the system and tools, but also to provide simple tasks which can be proposed before engaging the patient in the complex task. An example of primary task is "take a glass and put it on the table". A limited number of actions of the participant are necessary to achieve a primary task. Complex tasks (CT) are vIADL such as "coffee preparation". They require both planning of steps and spatio-temporal organization.

The CT task that we developed in the TVK is the preparation of a coffee. Graduation of the task is ensured by various parameters, like: 1) number of cups to prepare (from one to six), for counting requirements; 2) time's constraint, for time organization and stress induction; and 3) position of the required items (easy: all are ready at the right place; medium: all are on the table; hard: necessity to fetch all the items in the cupboards or in the drawers), for change of difficulty. The number of steps of the task depends on items positions and nature of the coffee (easy: 12 steps; medium: 14 steps; and hard: 16 steps).

2.3 *The virtual assessment grid*

Kerpape therapists use an assessment grid related to the coffee preparation task that was locally developed (Jouadé, 2003). It includes 16 types of errors: 6 actions errors (e.g., action omission) and 10 behavior errors (e.g., difficulty in decision making).

A part of the Kerpape assessment grid was computerized. Actually, the TVK can record 10 types of errors including of 6 actions errors (actions omissions, actions not completed, perseveration, sequence errors, actions additions and control errors) and 4 behavior errors (error recognition, difficulty in decision making, dependence, no use of therapist's help). The six actions errors can be automatically interpreted and recorded by the system in the virtual assessment grid. The four behavior errors must to be interpreted by the therapist and then can be recorded in the same grid after the therapist presses a keyboard key. If the patient needs instructions recall, he can press the SPACE key, and then the system records a dependence error.

We did not take into account the six other behavior errors of the real assessment grid (e.g., not appropriate behavior) because their interpretation by the therapists is still too subjective.

3. EXPERIMENTS

The goal of the two experiments we carried out was to explore the functioning of the TVK and the feasibility of the complex coffee task with healthy subjects (Experiment1) and patients with brain injury (Experiment2).

3.1 *Participants*

Participants of Experiment1 were 13 Kerpape Center employees (control group) (11 F, 2 M, mean age: 39 ± 6 years). They were recruited among the center staff: 2 neuropsychologists, 4 occupational therapists, 1 clinician, 2 physiotherapists, 1 orthoptist, and 3 center employees.

Participants of Experiment2 were selected among Kerpape patients with brain injury, according to 9 inclusion criteria (e.g., score of BDVO (Battery of visual decision of objects) > 67/76) and 10 exclusion criteria (e.g., Pregnancy). Seven patients (3 F, 4 M, mean age: 34 ± 17 years) were selected: 4 patients after TBI (1 F, 3 M), 2 patients after stroke (1 F, 1 M) and 1 meningoencephalitis (F). Two of them (P5 and P7) never played computer games.

3.2 *Procedure*

We carried out the experiments according to the following procedures:

Experiment1:

- Familiarization session: each participant experiments 7 primary tasks (4 tasks : take an item and put it on somewhere; 3 tasks : take a container and fill it up with water);
- Assessment session: each participant experiments 1 among 8 configurations of the complex task;
- Questionnaire on material use and task understanding;
- Moreover, 3 participants on 13 tested the configuration interface in order to create various configurations of the complex task and filled out a questionnaire about the use of the configuration interface for therapist.

Experiment2:

- Familiarization session: each participant experiments 9 primary tasks (3 tasks : take an item ; 3 tasks : take an item and put it on somewhere; 3 tasks : take a container and fill it up with water);
- Assessment session:
    - Familiarization recall : each participant recalled 3 primary tasks (take a cup; take the bottle of milk and put it on the table; take the carafe and fill it up with water);
    - Assessment: each participant experiments 1 configuration of the complex task (Preparation of a black cafe during 20 minutes);
- Questionnaire on material use and task understanding;
- The virtual assessment grid was automatically filled out by the TVK software;
- The real assessment grid was filled out by therapist.

3.3 *Data analysis*

For both experiments, a descriptive analysis of the data was performed. In Experiment2, we did two comparisons: one comparison was about results of 3 PTs to find out patient's performance after one repeat on two sessions, the other comparison was about two assessment grids (real vs. virtual) to find out the difference and then to valid the virtual one. An analysis of questionnaire for each group (control group and patient group) was done to test the feasibility of the tasks and the software TVK.

4. RESULTS

4.1 Experiment1

All the 13 participants of the control group succeeded in completing the primary and the complex tasks. Particularly, we took into account the time needed to achieve the various tasks. Range of values are: 1) [31sec, 2 min 47 sec] for the primary task "take an item and put in on somewhere" during the familiarization session; 2) [40 sec, 3 min 40 sec] for the primary task "take a container and fill it up with water" during the familiarization session; and 3) [5 min 30 sec; 17 min 36 sec] for the various configurations of the complex task during the assessment session.

4.2 Experiment2

All the 7 patients succeeded in completing the primary tasks when they were asked to do them, except Patient 7 who failed on 3 primary tasks of the familiarization session. Particularly, we took into account the time needed to achieve the various tasks and the number of errors made by patients. A comparison on 3 primary tasks during familiarization session and familiarization recall in assessment session is showed on Figure 3 and Figure 4. In these two graphics, we found out their progresses according to mean time and number of errors on both sessions. That's mean that their capacities to perform the primitive tasks were maintained, see the improvement from the familiarization session to the assessment session.

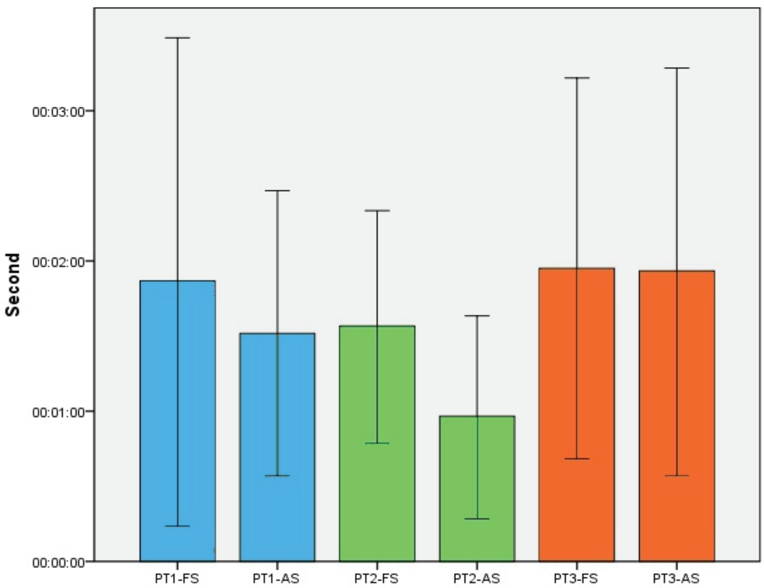

Figure 3. *Mean time of each primary task for 7 patients on both sessions (FS and AS)*

*FS: Familiarization session AS: Assessment session

*PT1: take a cup PT2: take the bottle of milk and put it on the table PT3: take the carafe and fill it up with water

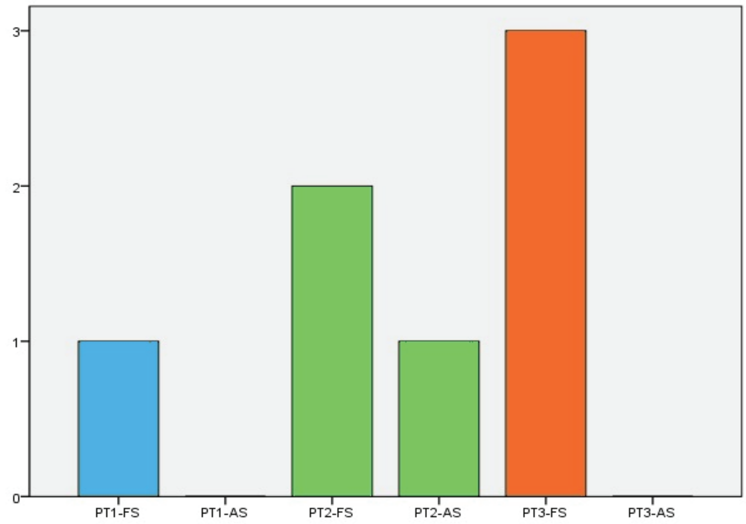

Figure 4. *Number of errors of 3 primary tasks for 7 patients on both sessions (FS and AS)*

In the assessment session, 5 patients on 7 succeeded in the completion of the CT (See details data in Table 1). The mean time of completion is 11 min 43 sec (± 7'37″). The patient6 did not repeat PTs before complete the CT. Finally, he had a problem to finish the task. The patient7 wasn't able to finish the CT at the end of 20 min. All of patients didn't disconnect coffee machine (Step 15).

Table 1. *Patients' data recorded of the task "coffee preparation" in the TVK*

N°	Age	Sex	Know PC games	Time (minute)	Number of errors	Number of executed steps		Omission
						Without errors	With errors	
1	20	F	well	4'33"	2	11	1	Step 15
2	19	M	well	2'45"	2	11	1	Step 15
3	48	F	medium	15'01"	9	9	3	Step 15
4	23	F	well	20"	21	8	4	Step 15
5	55	M	never	16'15"	6	8	4	Step 15
Mean				11'43"±7'37"	8±8	9±2	3±2	

* Number of executed steps (without and with errors) + omission = 13 (13 necessary steps to preparing a black coffee)

In the same virtual assessment for 7 patients, 40 errors were reported by the therapists in the real assessment grid (RG) and 61 errors were recorded by the TVK in the virtual assessment grid (VG) (Table 2). Comparison of these two grids is so complicated. But we tried to find out the difference between two grids. Our purpose is to unite therapists' interpretation in the TVK. There are two possibilities in the difference: missing of patient's errors and different interpretation between therapists. Research on missing of patient's errors isn't included in our study. For example, the patient4 realized 3 "Control errors": measured water for 8 people instead of 3; put 6 spoons of coffee in the coffee machine; poured 2 cups of coffee. But her therapist didn't note anything in the RG. Different interpretation between some therapists and the TVK is our research pivot. We list some differences below:

- After patient's correction, some therapists interpret still errors. The TVK don't record "actions omissions" after correction (e.g., the patient3 tried to turn on the coffee machine before fill up with water. Finally, she corrected).
- When one person didn't finish the task, some therapists stop interpreting immediately. But the TVK put an "omission" for all rest steps. For example, the patient7 wasn't able to finish the task at the end of 20 min.
- In order to interpreter the error "Action not completed", it must to definite an initial action and a terminal action for each step. So there are some different definitions of initial actions or terminal actions between therapists. For example, the TVK recorded an "Action not completed" for the patient7 on the step1 (take water) because he didn't close the coffee carafe before put it on the coffee machine. But his therapist didn't interpret as an error.

- There is a different definition about the error “Actions additions” between the TVK and some therapists. In general, it should not touch all objects except for the coffee task. If you touch a useless object, that must be noted as an “Action addition”. For the TVK, useless objects don’t include wall, table, cupboard, etc.
- About the type of errors “Perseveration”, if a patient tries to turn on the coffee machine *several* times before connect it (the button doesn’t change the color to red), the TVK interpret 1 “perseveration”. But most of therapists don’t think so. The patient4 and the patient5 currently are the case.

We have to explain why the number of errors in two grids was the same for the patient1: because her therapist (one of authors) participated in the design of the TVK. For the patient6, there is zero error in the RG and 6 errors in the VG. We can’t simply say that these 6 errors are ‘true’ errors or ‘false’ errors. It just depends on therapist. This difference between the real and the virtual assessment will help the Kerpape therapists to unite their interpretation of errors.

Table 2. *Number of errors in two assessment grids (real grid and virtual grid)*

N° P	Actions omissions		Actions not completed		perseveration		Sequence errors		Actions additions		Error recognition		Control errors		Difficulty in decision making		Dependence		No use of therapist"s help		Total	
	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG
1	*1*	*1*															*1*	*1*			*2*	*2*
2		1						1													0	2
3	7	1						5				1	1	2							8	9
4	2	1				1	*3*	*3*	3	1	*3*	*3*		3			*9*	*9*			20	21
5	2	1				1		3			*1*	*1*									3	6
6		2		1										2				1			0	6
7	2	6		1				4	1								*4*	*4*			7	15

* When RG=VG, the number of errors is in red and Italic

After an analysis of two questionnaires filled by health subjects and patients with brain injury, we found out that:

- The parameter setting of the configuration (time constraint, number of cups of coffee to prepare, positions of objects) is very useful for therapist.
- The PTs and the CT are understandable and interesting for two groups.
- The use of materials and interaction are very simple for the people who had computer games experience. It’s moderately difficult for the others.
- Different helps (mouse visual cues, display instruction on screen) are understandable even for patients without experience.
- The task “coffee preparation” is not useful for everybody because 2 patients on 7 don’t usually drink coffee.

4. DISCUSSION AND CONCLUSIONS

We reported a preliminary study that validates the feasibility of the TVK with healthy subjects and patients after stroke or TBI as well as the delivery of a final virtual scale of evaluation based on the traditional scale used in the Kerpape Rehabilitation Center. The experimental results obtained support our hypothesis. 1) It’s possible to computerize a daily life task (coffee preparation). It really worked in the TVK. 2) Patients with brain injury or health subjects are able to complete the virtual CT. Interestingly, the use of materials and virtual interaction are not very difficult for some patients. It’s not like we suppose before. It’s depends on the participant (health subject and patient) who has or hasn’t computer games experience. In this study, we had two difficulties on real and virtual assessment. Actually on real assessment, it’s difficult to unite define and accurate measure errors for therapist. The variability of interpretation of errors by the therapists was protruded. On virtual assessment, it’s difficult to observe behavioral errors (e.g., not appropriate behavior) for a simple computer system because their interpretation is still too subjective. This research has investigated again the potential of using VR in therapeutic area: identification and characterization of deficits; subjective measure; performance review and unite interpretation of errors for all therapists.

The Kerpape therapists are providing their assessment grid and uniting interpretation of errors. The achievement of these developments will provide novel therapeutic practices to our clinical partners. Two future goals are to provide software compatibility with instruments that allow collection and analysis of behavioral data, such as eye-tracking devices and sensors for psycho-physiological monitoring and to investigate how capacities learned in a virtual task can be generalized to the same task in the real world.

Acknowledgements: We thank Laval authorities (Laval Agglomération and Conseil Général de la Mayenne) for their support and Emissive company for the 3D modeling of the TVK.

5. REFERENCES

B M Brooks, F D Rose, J Potter, S Jayawardena and A Morling (2004), Assessing stroke patients' prospective memory using virtual reality, *Brain Inj*, **18**, 4, pp.391-401.

R C Davies, E Löfgren, M Wallergard, A Linden, K Boschian, U Minör, B Sonesson and G Johansson (2002), Three Applications of Virtual Reality for Brain Injury Rehabilitation of Daily Tasks, In *International Conference on Disabilities, Virtual Reality and Associated Technology*, Hungary.

C M Fidopiastis, C B Stapleton, J D Whiteside, C E Hughes, S M Fiore, G A Martin, J P Rolland and E M Smith (2006), Human Experience Modeler: context-driven cognitive retraining to facilitate transfer of learning, *Cyberpsychol Behav*, **9**, 2, pp.183-7.

S Fortin, L Godbout and C M Braun (2003), Cognitive structure of executive deficits in frontally lesioned head trauma patients performing activities of daily living, *Cortex*, **39**, 2, pp.273-91.

O Godefroy (2003), Frontal syndrome and disorders of executive functions, *J Neurol*, **250**, 1, pp.1-6.

A S Jouadé (2003), Evaluation écologique de l'exécution de routine d'actions chez des patients dysexécutifs., In, Edition30. Mémoire de Diplôme d'Etudes Appliquées à l'Université d'Angers.

N Katz and A Hartman-Maeir (2005), Higher-level cognitive functions, In *Cognition and occupation across the life span* (N Katz), AOTA Press, Bethesda, MD, pp.3-26.

E Klinger, I Chemin, S Lebreton and R M Marié (2006), Virtual Action Planning in Parkinson's Disease: a control study, *Cyberpsychol Behav*, **9**, 3, pp.342-347.

E Klinger, X Cao, A S Douguet and P Fuchs (2009), Designing an ecological and adaptable virtual task in the context of executive functions, In *Studies in Health Technology and Informatics (SHTI) series* (B Wiederhold and G Riva), pp.248-252.

P Pradat-Diehl, A Peskine, M Chevignard, C Taillefer, C Picq, F Poncet and P Pradat-Diehl (2006), *Évaluation des troubles neuropsychologiques en vie quotidienne*, Springer Paris, Paris.

A A Rizzo, M T Schultheis, K A Kerns and C Mateer (2004), Analysis of assets for virtual reality applications in neuropsychology, *Neuropsychol Rehab*, **14**, pp.207-239.

A A Rizzo, T Bowerly, J G Buckwalter, D Klimchuk, R Mitura and T D Parsons (2006), A virtual reality scenario for all seasons: the virtual classroom, *CNS Spectr*, **11**, 1, pp.35-44.

F D Rose, B M Brooks and A A Rizzo (2005), Virtual reality in brain damage rehabilitation: review, *Cyberpsychol Behav*, **8**, 3, pp.241-62; discussion 263-71.

L Zhang, B C Abreu, G S Seale, B Masel, C H Christiansen and K J Ottenbacher (2003), A virtual reality environment for evaluation of a daily living skill in brain injury rehabilitation: reliability and validity, *Arch Phys Med Rehabil*, **84**, 8, pp.1118-24.