Managing a dual-task during a virtual shopping in patients with early dementia.

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Abstract: - Neuropsychological assessment of executive functions with paper and pencil tests is particularly sensitive to the lack of ecological validity especially if the purpose of the clinician is not to get a merely theoretical measure, but to assess the deficit impact on patient's life. The classical ecological measure provided by the direct observation of the patient in his daily life can be more informative even if this practice can be unsafe for patients and difficult to implement. In order to maintain an enactive cognition perspective on the study of cognitive functions, in which the role of interaction between the embodied behaviors and the affordances provided in the coupling with the environment have a fundamental role, we introduced an ecologically like situation by means of virtual reality. This paper presents a virtual reality test, set in the scene of a supermarket that can be a valid tool to assess executive functions in dementia. The results show that the test has convergent validity, compared to the Mini Mental State Evaluation and Tower of London tests and discriminant validity in identifying the degenerative disease, compared to healthy subjects matched for age, sex and education.

Key-Words: - **Dual-Task, Virtual Reality, Dementia, Alzheimer's disease, Clinical Neuropsychology Embodiment, Executive Functions,**

1 Introduction

Disorders of executive functions are one of the most frequent cognitive deficits in the elderly and in the early stage of dementia. The term is generally used to define a complex of various cognitive processes that to date seems to be not comprehensive of a unitary and well-defined concept [1]. The term was conceived for the first time by Luria in 1966 and includes several complex cognitive functions such as behavior planning and activity monitoring. Moreover executive functions are generally described as involved in strategic cognition, such as solving multiple tasks, modifying action plans in the light of new information acquired, generating sequential behaviors for achieving goals or execute complex body movements in space. Thus, a definition of executive functions could include a cognitive flexibility and also the ability to pay attention to the task in place, filtering and excluding interference. In sum it refers to the cognitive ability to put in place behaviors aimed at achieving a goal and at the same time the ability to foresee the consequences of performed actions [2]. It also seems that the coordination, control and target orientation are key concepts in the definition of executive functions. The prefrontal cortex plays a key role in the regulation of executive functions and there is evidence that other brain areas are also involved in this flexible cognitive domain [1]. Neuroimaging researches have shown that even the posterior regions of the cortex and subcortical ones seem to have a role in executive functions [3]. Accordingly it appears that the executive functions are not localized in a single region of the brain, but rather that they are mediated by dynamic neural networks [2]. In more recent years, Baddeley [4] coined the term "dysexecutive syndrome", including deficit in complex action planning, impairments in organizational behavior, disinhibition and perseveration in simple actions. Deficits in executive functions can be observed even in patients without a clear impairment of the frontal lobes.

By considering in particular that frontal lobes are particularly prone to deteriorating in elderly population, the research have largely investigated the link between dysexecutive syndrome and aging [5]. The importance of a good executive functioning is even more relevant in those individuals who have been diagnosed to be cognitively impaired: this is the case of patients characterized by a clinical condition known as dementia. Dementia can be considered as an important condition in which patients are characterized by difficulties in one or more cognitive domains, usually the memory one, which has a relevant impact on their everyday functioning. Several authors revealed not only that different subtypes of dementia exist [6], but also that even this kind of patients could show issues in everyday life activities [7]. In details, scholars have found that impairments could strike these patients in different ways, distinguishing among them accordingly to the type and quantity of cognitive domains involved. Interestingly, recent studies have found out that even amnesic single- domain patients, who were deemed to be the least impaired ones, could show executive dysfunctions both in laboratory and ecological contexts [8]. Hence, since these findings are quite recent ones, it seems to be useful and necessary to further investigate executive abilities in dementia patients. Moreover the most recent literature showed how there is evidence of breakdown in executive functions even in the early stages of Alzheimer's disease (AD). Indeed, what seem to be memory problems may instead be problems in attention, and people with AD may have impairments in their ability to pay attention to relevant information rather than irrelevant information, which can contribute to memory deficits. Many authors have investigated the effect of aging on dual-task performance, that is an aspect of executive functioning on the control of attention when performing concurrent tasks [6]. It was observed, in fact, to decline with normal and pathological aging. Many different cognitive models have considered these difficulties, referring to them as a decline in processing speed, lack of attentional resources and coordination ability. These models are generally referred to as "resource reduction models". One important finding is that older adults are less effective than younger ones in the rapid reallocation of attention when performing two or more tasks [9]. This difficulty can be related to task complexity and the execution of more than one tasks simultaneously represents only one aspect of the problem. Accordingly a dual-task paradigm has been a key topic in recent years due to the importance of being able to attend to multiple, and often conflicting tasks in everyday life. The evaluation of the divided, sustained and selective attention, of the problem solving and of the errors detection abilities can be conceived as a part of executive function neuropsychological intervention, aimed at correctly assess impairments and support high level functions by means of adequate ecologically tasks.

Due to the complex and situated nature of this cognitive domain the ecological validity of executive functions neuropsychological tests has been largely questioned. The key assumption is based on the consistency between performances on laboratory tests with patients' everyday executive functioning abilities. Accordingly in order to better reflect the impact of a dysexecutive syndrome in patient's everyday life, an ecological assessment is generally requested. Executive functions, in addiction, provide peculiar opportunities for the evaluation of the ecological impact of disease in neurological patients because it requires a pervasive challenge of everyday life. It consists, in fact, of performing successive (e.g., changing a plan of action based on a second stimulus) or simultaneous (e.g., driving and conversing, or listening while note-taking) tasks. The importance of such functioning for independent living in young and old age has lead to a rich output of empirical work since the early 1960s. This topic has been studied from several points of view, both in healthy individuals and those suffering from brain damage, including cognitive models of mental functioning, neuro-imaging studies and neuropsychological interpretations.

Contrariwise panorama on classical executive functions assessment and treatment is so unlike everyday situations, that knowledge of performance in it is of very little help for assessment since it is of uncertain predictive validity (or "generalizability"). Specifically at present we do not really know what situations in everyday life require the abilities that the classical neuropsychological tests measures. This situation is largely repeated for most other popular measures used to investigate executive (i.e., “frontal lobe”) function. For example, one of the test that has been generally considered to be a measure of planning, the Tower of London test (ToL - [10]) is now doubtful because the task failure in frontal lobe patients could not be clearly be characterized as a planning impairment (see [11] for a review). Moreover, what the ToL measures may in any case have little relevance to “real-world” planning. The situation that the test performance during the neuropsychological assessment presents to the participant is quite unlike most situations that will be encountered outside it (i.e., they show poor “representativeness”). This laboratory investigation, in fact, uses tasks that are simplified “models of the world” to make the problem scientifically tractable and deliberately designed to have characteristics abstracted to those encountered in everyday life. However it is not at all clear which cognitive ability evaluation are represented by tasks and which is its ecological validity. And in clinical work, we cannot ignore the necessity of knowing how the abilities one is measuring translate into behavior outside the laboratory.

With the introduction of virtual reality (VR) tools it has become possible to evaluate patients’ performances while they are exposed to a more ecologically relevant situation [12]. The use of computerized tools, and in particular VR, presents specific challenges: First of all the adaptability to varying user abilities. Second, they enhance a high level of engagement and motivation. Third, the repetitive training that may be used not only during hospital sessions but also in rehabilitation at home. Finally its multi-sensorial stimulation and feedback produce more realistic tasks that are safe and suitable for cognitive assessment [13]. Moreover the realism and engagement of VR tools may also help to transfer learning to the not simulated world.

In the present contribution we present an executive functions assessment with the use of a VR scenario. We start from the assumption that there are experiential differences between the execution of a laboratory test and the everyday behaviors and we would like to understand if these experiential differences might influence executive function assessment.

By adopting the enactive perspective to interaction we reconsidered the characteristics of the coupling between an agent and its environment during the executive functions evaluation. It implied to deeply define the link that will involve reciprocal modifications between them, and to clarify the conditions for reciprocal changes. Accordingly we translated the main principles of the classical executive functions neuropsychological tests (ToL included) in a virtual reality environment. Within this new enactive test based on a virtual reality simulation agents will be able to interact by choosing appropriate affordances according to their embodied perception of such environment. Moreover we aim to gain information from this peculiar sensorimotor coupling in order to support subjects in creating representations of the world in terms of body-environment invariants. Finally according to the enactive perspective in this paper we would like to investigate how this coupling can differ within two different subjects populations: adult/elderly people and Alzheimer’s ones.

2 Materials and method

2.1 The virtual environment

We choose to develop a supermarket scenario via the NeuroVR software (www.neurovr.org, [14]). The subject-environment interaction was based on semi-immersion mode. Accordingly scenes were visualized on a large screen via video-projector and interaction was possible by a joypad. The virtual platform enables the active exploration of the 3D scene where users are requested to select various products presented on shelves. The subjects enter the supermarket where they were presented with icons of the various items to be purchased. Participants were allowed to freely navigate in the various aisles (using the up-down joypad arrows), and to collect products (by pressing a button placed on the right side of the joypad), after having selected them with the viewfinder. Audio announcements are available and can be used to introduce additional tasks while the users were engaged in their primary task (shopping 4 items from a list of products provided to them by the clinician). The virtual supermarket contains 96 shelves distributed over 12 product sections. Each shelf is filled with six items of the same product. Products are grouped into the main grocery categories including beverages, fruits and vegetables, dairy, meat, breakfast foods, canned goods, hygiene products, snack foods, frozen foods, garden products, animal products, and stationary supplies. Signs at the top of each section indicate the product categories as an aid to navigation. An initial pilot study provided data concerning the selection of products that were most easily identifiable.

2.2 Procedure

With the aim of introducing a dual-task paradigm for the assessment of executive functions we established two main tasks that subjects have to satisfy: (1) a primary task according to which participants have to purchase a list of four supermarket products in a pre-set order and (2) a secondary task according to which participants have to temporarily modify the primary rule as dictated by an audio announcement. The list of products was written on a paper and available the participants for the duration of the task. Once a participant has satisfied the secondary rule, he then returns to complete the task in accordance with the primary rule. The secondary rule increases in its difficulty with respect to the collection order and number of items, in increasingly complex combinations. Specifically, the initial three trials (1 to 3) consisted of a simple collection task. The main task consists of collecting the products written in the list, by following the specified order.

After, the following trials involved a change to the primary rule, in terms of the order of items to be collected. In trials 4 to 6 participants hear an audio announcement, requiring a change in the order of products to be collected. First, they have to take the specified product, and after that to return to collect products following the list order. No more than an item of each product in the list have to be collected.

Then, a different change in the primary rule was introduced referring to the number of items to be collected. In trials 7 to 9 the audio announcement modify the number of a product to be collected. Participants have to maintain the specified order of collection, remembering the new number of the target product when they are approaching it.

Finally, a combination of order and number of objects to be collected is added as secondary rules. In trials 10 to 12 two audio announcements are presented. One will modify the order of collection, while the other will modify the number of products to be collected. First, participants have to take the product which has the priority, then to collect the other products in the specified order, by remembering the new number of the products specified by the announcement. At last a final trial (number 13) was added, constituted by the same combination of order and number, with more than two objects involved in the change. It represents an higher level of complexity, introduced in order to investigate participants performances in a more complex situation, providing interesting information to be used for further investigation.

Once the primary rule is completed successfully for at least two out of three trials, the secondary rule is introduced by playing an audio announcement (e.g., rule 2, trial 4: *"Milk supplies are almost out, please proceed now to the dairy shelf"*). The announcements are played before the participant starts to take items from the shelves. Thus, if he is unable to complete the task when confronted with the secondary rule, the same trial, but with different objects, is presented until he is able to accomplish it for at least one out of three attempts. A trial is considered correctly completed only when the subject commits no errors.

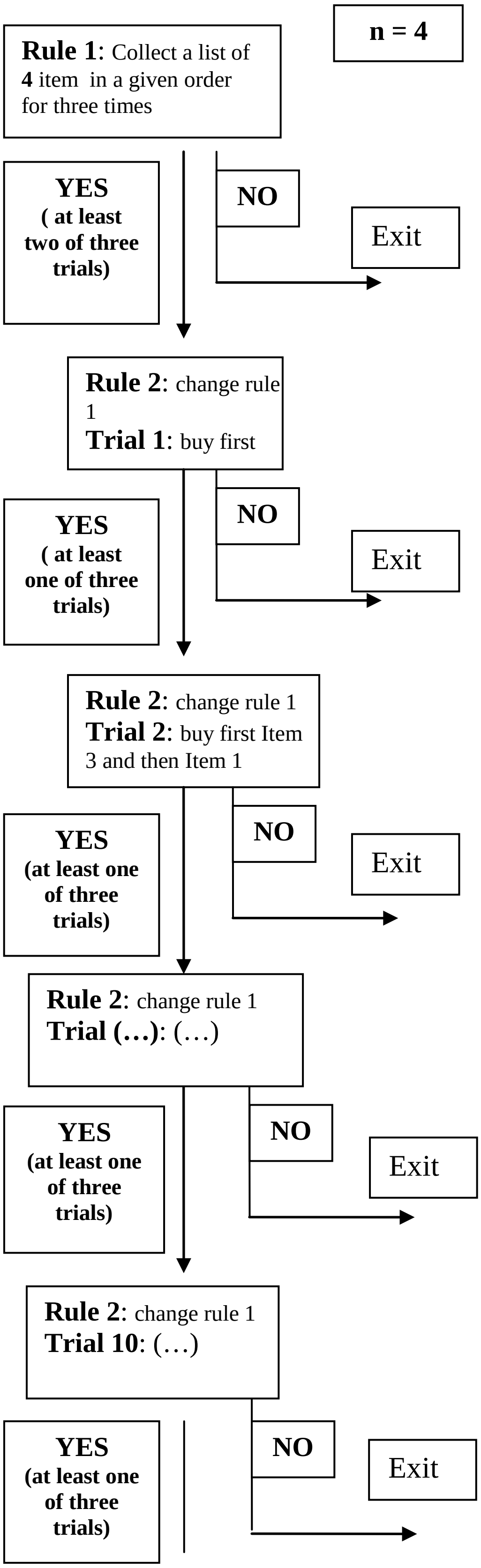
A detailed scheme of the procedure is depicted on Figure 1.

A training period was first provided in a smaller version of the virtual supermarket environment in order to familiarize participants with both the navigation and shopping tasks. Then the subject explored virtual supermarket customized for the dual-task for 10 minutes, while the experimenter pointed out its main features. Participants were requested to practice navigation and object recognition. The subject then performed the series of single- dual-task conditions as described above. The assessments and training session took about 75 minutes. If the subject was unable to achieve success in training and exploration phase, the experimental procedure wasn't run.

2.1.1 Outcome measures

Execution times and errors were recorded for each trial or attempt (when subjects needed more than an attempt to complete a trial), by separating execution time referred to successful and unsuccessful trials. Time is stopped between the different attempts, if needed, and then the total time is calculated by adding each attempt execution time. For errors calculation we applied a 0-4 range for evaluate between not executed to optimally executed trials. The evaluation for each trial is computed and analyzed for each cluster of trials (rule1; rule 2-order, rule 2- quantity; rule 2- order and quantity). We also recorded the number of trials failed and the complexity level reached by each subject (the highest level completed successfully within the number of attempts allotted for the trial).

Figure 1 – Dual task procedure in the virtual supermarket



2.3 Subjects

We administered the procedure to 72 voluntary subjects (35 Alzheimer's patients and 37 healthy individuals) who obtained MMSE scores between 16 and 30 (Mean 25,54; sd 3,36) and who ranged in age from 50 to 80 years (Mean 70,25; sd 11,23). They are balanced within the groups for gender (47 female; 25 male).

3 Results

Descriptive statistics were used to summarize the variables. Execution times, errors and complexity level were analyzed for each trial in order to identify the maximum complexity level of tasks that participants were able to carry out according to their group (AD/healthy).

The mean execution times for the entire task shifting procedure (a total of 13 trials) equaled 41,55 minutes (sd 8,4) with a mean of 4,3 minutes to complete each trial.

Subjects made a mean of 10,31 score (sd 6,56) over the 13 trials, which were divided into order error (the collection of an item in the wrong order with respect to the instruction) and number errors (the collection of more or less items with respect to the number specified by the instructions, or the collection of the correct number of a wrong object, or the collection of one item more than one time). The first type of error is generally expected during trials 4-6 and 10-13, while the second type of error is expected during trials 7-9 and 10-12 in accordance with the type of rule imposed. The results showed that the mean number of errors from each type was 2,51 (sd 1,75) for order, 1,90 (sd 1,82) for quantity and 2,47 (sd 2,71) for order and quantity.

The comparison between AD and adult/elderly groups revealed significant differences between them for all the cluster of trials (rule 2-order $p < .001$; AD 1,23 /healthy 3,73; rule 2- quantity $p < .001$; AD 0,91 /healthy 2,84; rule 2- order and quantity $p < .001$; AD 0,91/healthy 3,95).

At last performances on virtual supermarket appear to correlate with MMSE (Pearson's r .669) and ToL (Pearson's r .691).

4 Conclusion

Over the past twenty years progress in technology has provided clinicians with new opportunities for evaluation and treatment of neuropsychological disorders, which were not available with traditional methods. The introduction of a virtual reality simulation with elderly people and with dementia patients showed a great potential for the evaluation for the assessment of everyday life activities that involve executive functions. The use of simulated environments was perceived by the user as quite comparable to real world objects and situations and overcome the limitations of the traditional neuropsychological assessment, by keeping intact its several advantages. From our data it seems that in healthy individuals the first three experimental trials (when the primary rule was enforced alone) gave subjects an opportunity to become adept at the paradigm. That is, it served the function of a training tool to re-calibrate the sensorimotor coupling with the virtual environment in preparation for the dual-task procedure. The collection of the four items in the correct order for three successive trials enables subjects to become accustomed to the initial technological conditions and to concentrate on task execution. All subjects reported that they felt more confident with the use of the joypad after several trials, and quickly became more engaged in the task and found it to be enjoyable. We also noticed the absence of any need for prior experience with the use of a computer and peripheral devices and the level of involvement in the dual-task procedure; on the contrary, many persons indicated their enjoyment in performing a novel task. It doesn't appen for the AD population for with every trial was experienced as novel one. Accordingly observation of subject performances indicated that the performance appeared to be related not only with the ability to interact with a computer device like the joypad (as expected) but also with visual-spatial memory and the ability to categorize the objects into groups useful for the collection task. In fact, on the basis of our qualitative observations, we suggest that people who could memorize the positions of items in the training phase and who utilized the panels to identify the location of the products seemed to complete the task faster than persons who did not apply such a strategy.

A methodological question about the ecological validity in neuropsychological assessment can be issued. Spooner and Pachana [15], in fact, consistently with the more recent neuroscience methodologies – such as neuroimaging techniques --attribute a different function to neuropsychological assessment. Where once clinical neuropsychology has played a key role in the localization of brain functions, grounding it on the dissociation between clinical cases and specific cognitive consequences of brain damages, at moment PET and functional MRI play a better role for the anatomical location. For this reason the role of neuropsychological assessment should be partly revised as mainly addressing the early diagnosis of certain types of cognitive decline which are indicators of the activity of multiple brain regions or 'neural systems', which may limit their precision at localization. Rather than lesion localization, in fact, the main purpose of neuropsychological assessment should be to draw conclusions from assessments regarding patients' abilities to living independently or returning to a previous occupation. This issue is extremely important especially in the cognitive assessment of elderly population in which we can individuate several "borderline" situations not always detectable from a classical neuropsychological assessment. Specifically it is important to gain a greater understanding of the nature of age-related difficulties in everyday cognition mainly because the age-associated limitations on it could potentially lead to restrictions in daily activities especially if they are performed in new environments. Despite this evidence in daily cognitive decline and its role in the difficulties experienced by older adults is grossly underestimated.

In conclusion, as enaction introduces the notion of the coevolution of the agent and its environment here we introduced a peculiar body-environment coupling by using virtual environments that can give us more info about executive functions impairment than abstract planning tasks as in the classical neuropsychological tests. This difference can be partially attributed to the participant's sensation of "being there" in a simulated environment rather than in a natural one. Accordingly, in virtual reality, individuals can experience atypical patterns of sensorimotor coupling that might influence their ability to catch appropriate affordances for action in context. If our argument is correct, these kinds of programms are the most likely sources for the next generation of "executive function" clinical tests providing ecologically like scenarios. This argument should not be mistaken as suggesting the sole use of tests that are carried out in the "virtual worlds" or that such tests will necessarily prove more clinically useful than others, especially when practical ecological validity concerns are taken into account. Instead the argument here is that one should consider in the design of new tasks the demands that the "real world" may make but that are not presented to the participant performing existing tests in a lab setting. By not considering these aspects, we may be missing decrements in many aspects of cognition that are critical to competence in everyday life. Some progress has been made in various areas of neuropsychology, but with few exceptions in the field of executive function, this is not the provenance of the most prevalently used task.

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