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Virtual Reality based tools for the rehabilitation of cognitive and executive functions: the V-STORE.

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ABSTRACT

Cognitive rehabilitation is represented by the application of a lot of procedures in order to enhance development of skills and strategies necessary to overcome cognitive deficits. Computer-based tools can be fruitfully used in the assessment and rehabilitation of cognitive and executive functions. In particular Virtual Reality could play a key role in the rehabilitation of psychological functions due to a creation of synthetic environments where it is possible to carry on tasks very similar to the ones experienced in real contexts. After an analysis of the main characteristics and open issues of the PC and VR based cognitive rehabilitation, the major aim of this paper is to describe: a) the rationale for the use of Virtual Reality in this field and b) some VR tools (V-Store, V-Tol, V-Wcst) used with a particular category of dysfunction, the Dysexecutive Syndrome, typical of the patients with frontal lobe injuries and other neurological diseases. In particular the description of V-Store is provided.

Keywords: *Virtual Reality, Cognitive Rehabilitation, Dysexecutive Syndrome, Frontal Lobe Syndrome, computer-based tools.*

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1. Open issues about computer-based cognitive assessment and rehabilitation.

Cognitive rehabilitation is characterized by the application of a lot of procedures by a different group of professionals such as neuropsychologists, occupational therapists,

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speech pathologists. These procedures aim at enhancing the development of skills and strategies necessary to overcome cognitive deficits (Diller & Gordon, 1981; Ginarte Arias, 2002; Gontkovsky, McDonald, Clark, & Ruwe, 2002; Mickey et al., 1998; Riva, 1998a, 1998b), overall with persons characterized by traumatic brain injuries.

Cognitive rehabilitation techniques have a long history since the ancient Greeks, but only after the World War II they achieved a high level of spread and use in clinical units. According to Gordon, one of the main reasons that could explain the great expansion of cognitive rehabilitation in the latest years is represented by the fruitful technological applications and tools: the potential of computer-based tools could enhance the administration of cognitive rehabilitation (Gordon, Hibbard, & Kreutzer, 1989); (Mickey et al., 1998). Although the potential of computer-based techniques has been underlined (Bracy, 1983); (Gontkovsky et al., 2002), controlled research investigations of computerized interventions have not yet been conducted and concluded (Gordon et al., 1989; Mickey et al., 1998).

Computer-based tools could be fruitfully used in the assessment of cognitive functions too. In particular the Tower of London (TOL) Test (Shallice, 1982) has been studied by Morris et al. (Ager, 1993) in order to obtain a computerized version of TOL, using a touch-screen. The main advantage of this PC version was the possibility to carry on a more detailed analysis of the performance due to the registration of all the movements (and relative times) produced by patients. Also the Wisconsin Carding Sorting Test (WCST) (Berg & Simple, 1948) has been studied in order to obtain different computer-based versions (Grant & Berg, 1984; Nelson, 1976) such as the Bexley-Maudsley Category Sorting Test (Acker, 1982). The advantages of these computerized tests are many: to save time in the scoring step, to simplify all the procedures, to create and show new integrates multi-media scenarios more similar to reality than the traditional pen and pencil approach (Gourlay, Lun, & Liya, 2000).

About rehabilitation, the use of computer-based techniques is now one of the most promising and discussed field of research. There are a lot of open issues related to efficacy, ethics and ecological validity.

First of all the evaluation of the results of computerized rehabilitative techniques is not always univocal due to methodological problems, such as the difficulty to plan comparison between more groups of patients that can differ for a lot of variables very hard to control (such as social, cultural and environmental stimuli, spontaneous retrieval, efficacy of other contemporary treatments, different neurological, cognitive and behavioural situation before the rehabilitation, etc.). Moreover many studies in rehabilitation fields do not include control groups (Mazzucchi & Maravita, 1993).

Another open issue is represented by ethical problems related to the possibility to experiment not yet validated rehabilitative protocols with patients that could receive more benefits using traditional approaches.

Moreover another point of discussion is about the ecological validity of computer-based rehabilitation procedures (Gourlay, Lun, & Liya, 2000; Riva & Gamberini, 2000). Are these techniques useful for patients' everyday life? Is there a realistic and efficacy transfer of knowledge between the tasks carried out in labs and the life outside the hospital?

There also recognized advantages in the use of computerized techniques in the rehabilitation. First of all many exercises made with a PC could be repeated as homework without the presence of therapists. Secondary, modern software allow "customized" programs that can be built according to single patient's characteristics: the computerized rehabilitative protocols and exercises are flexible and could be adapted on user's needs and features (Skilbeck, 1993).

According to Kurlycheck and Levin (Kurlycheck & Levin, 1987), also in our opinion PC based rehabilitative programs have to follow the indications reported below:

1. Providing tasks of growing difficulty.
2. Selecting a level of difficulty that allows patients to obtain a high percentage of success.
3. Controlling the accuracy and speed of responses.
4. Providing frequent feedback information in order to correct the wrong responses and to confirm the right ones.
5. Reducing gradually the suggestions.
6. Stimulating motivation, continuity and enterprise in patients.

2. The role of Virtual Reality in the cognitive rehabilitation

Among the different computer-based technologies, Virtual Reality plays a key role in the assessment and rehabilitation of psychological functions (Cunningham & Krishack, 1999), (Broeren, Bjorkdahl, Pascher, & Rydmark, 2002; Campbell, 2002; Gourlay, Lun, & Liya, 2000; Grealy & Heffernan, 2000; Jack et al., 2001; Merians et al., 2002; Piron, Cenni, Tonin, & Dam, 2001; Silva, 2002; Tarr & Warren, 2002; Zhang et al., 2001). According to Tarr, Virtual reality (VR) has finally come of age for fruitful applications in neuroscience, cognitive science and psychology. The VR attractive is due to improvements in computer speed and quality of different tools (head-mounted displays, wide-area tracking systems, etc.)(Tarr & Warren, 2002).

Moreover VR is considered as the most advanced evolution of the relationship between man and computers (Vincelli, 2001). VR is different from other technologies because it offers to users the chance to experience psychological states of *immersion* and *involvement* (A. A. Rizzo, Wiederhold, & Buckwalter, 1998) due to the combination of hardware and software tools with particular interactive interfaces (such as *head-mounted display* and *tracker*). So one of the possible added values of Virtual Reality (with respect to traditional electronic systems of representation and interaction) seems to be the particular level of *presence* that subjects can experience in virtual environments (VEs). With the present and future development of technologies, synthetic environments will be able to re-create situations more and more similar to the ones we experiment in everyday life, therefore we can easily imagine that the possibility to feel presence in virtual environments will increase.

Virtual Reality is a technology used in many applications, from health care to arts, from e-learning to entertainment. Focusing on the health care field, VR finds a role in many areas such as psychotherapy (assessment and treatment of pathologies such as social phobias, eating disorders, sexual disorders, depression, autism, etc.), cognitive rehabilitation (about memory, attention, spatial abilities and superior cognitive functions), motor rehabilitation (about paraplegia, parkinsonism and other disabilities). In particular, in the field of rehabilitation, the possibility to use new technologies has been studied (Gordon et al., 1989) and the potential of virtual reality based applications has been recognized (Pugnetti, 1998; A. A. Rizzo & J. G. Buckwalter, 1997).

According to Rizzo et al. (A. A. Rizzo et al., 1998), it is necessary to carry on a realistic cost/benefit analysis to evaluate which is the added value of VR in different applications comparing with traditional approaches. A key question is *does the objective that is being pursued require the expense and complexity of a VE approach, or can it be done as effectively and efficiently using simpler, less expensive, and currently more available means*? (A. A. Rizzo et al., 1998).

There are different issues to consider in order to evaluate the real costs and benefits of Virtual Reality in mental health applications. One of these important issues, in order to ensure high benefits in the use of VR, is represented by production of functional and useful environments. Traditionally, as indicated by Waterworth, VR designers typically aim at creating an engaging and convincing environment in which users feel present (Waterworth & Waterworth, 2001). The focus for VR developers seems to be "presence" and all the systems to improve it.

But the concept of presence is very complex because this psychological state is characterized by many factors and so a key issue becomes the choice of the presence factors that have to be considered in the use of VEs in mental health applications. Riva (2000) notes that the substantial challenge for the designers and users of VR is *how* to use immersive environments to support clinical practice (Riva, 2000). It becomes clear that a VE built for entertainment has to be different from a one use in psychotherapy or cognitive rehabilitation. So which are the core characteristics of a virtual environment in order to ensure a kind of presence that is functional and useful for mental health applications?

In Riva's opinion two key characteristics of VR as a clinical oriented tool have to be the *perceptual illusion of non-mediation* and the *sense of community*: in mental health applications, reproducing physical aspects of virtual environments may be less important than the possibility of interaction that a VE could allow. According to Riva, in clinical oriented environments "the criterion of the validity of presence does not consist of simply reproducing the conditions of physical presence but in constructing environments in which actors may function in an ecologically valid way" (p. 356, Riva, 2000). Thus the level of presence, connected with the functional use of VEs in clinical applications, depends also on the level of interaction and possible interactivity (Riva, 2000).

Table 1. Possible issues to consider in designing Virtual Environments in clinical applications.

Key questions	Possible answers	Applications and indications for VR designers
1. Are VEs useful, effective and efficient in clinical applications?	Evaluation of possible advantages and limits Cost/benefit analysis	Development of VEs that have to ensure only the level (and quality) of presence requested by each application.
2. Do VEs reproduce the	Attention on graphics and technical characteristics.	Development of VEs that have to ensure realism and a

physical and perceptual characteristics of real environments?	Focus on realism and technical issues	level of presence as non-mediation and immersion.
3. Do VEs allow users to function in an ecologically valid way?	Attention on cultural and social aspects. Focus on interaction, interactivity Importance of relationships and context	Development of VEs that have to ensure ecological situations of interaction, interactivity

3. The case of executive functions

In the field of disabilities, the category of cognitive dysfunctions can be classified making a distinction between the loss (partial or complete) of the basic *instrumental* cognitive functions (such as attention, memory, language, visual-spatial abilities, etc.) and the loss of *executive* functions (also called *central* or *control* functions). These are generally referred to a group of behavioural skills that includes: the ability of planning a sequence of actions, the ability of maintaining attention in time, the ability of avoiding the interfering stimuli and using the feedback provided by others, the capability of coordinating more activities together at the same time, the cognitive and behavioural flexibility and the other abilities used to cope new situations and stimuli (Crawford, 1998).

Many terms have been used to define this syndrome: *Disorders of Executive Functions*; *Dysexecutive Syndrome*; *Strategy Application Disorder* (SAD); *(Pre)Frontal Syndrome*. Loss of executive functions is primarily a consequence of brain injury located in the prefrontal cortex area, but many different categories of subjects can be characterized by the same syndrome and by similar symptoms, with different levels of severity and various forms of resulting behaviour: patients suffering of different forms of dementia (Alzheimer Disease, Frontal or Frontal-Temporal Dementia, etc.), patients with attention disorders and hyperactivity (i.e. ADD-H), subjects suffering of Schizophrenia.

Usually the problems related with cognitive disabilities are not evident: Thimble (1990) noted that the pathological conditions due to a frontal dysfunction, very often are not recognized in the clinical practice. This situation could happen, overall in the case of frontal lobe disease, because cognitive performance of subjects may not be significantly reduced and many traditional neuropsychological tests may fail to show significant dysfunctions in the patients' responses (Damasio, 1995; Gourlay, Lun, Lee, & Tay, 2000). For example the traditional version of Wisconsin Card Sorting Test (WCST)(Heaton & Pendleton, 1981) has been usually considered a key measure in the diagnosis of frontal lobe dysfunction (Bornstein, 1986; Braff et al., 1991; Drewe, 1974; Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Milner, 1963, 1964), but recently Stuss et. al noted that "this view of the WCST as a specific measure of impairment in the frontal lobes has also been seriously questioned" (p. 388, (Stuss et al., 2000).

As Damasio brilliantly pointed out, in the complex tasks of everyday life, the same patients may show great limits, decisional problems and inabilities connected with high levels of psychosocial suffering. It has been demonstrated that traditional tests of frontal lobes function may fail to document abnormality: this "diagnostic insensitivity" may cause problems between patients and health care services and can determine incapacity to predict the outcome of treatment.

Damasio's famous patient Elliot not only had normal performances in the standard "frontal" cognitive tests, but in the lab assessment he showed normal responses to the proposed social situations, he planned strategies and he demonstrated to be able to evaluate correctly the consequences of actions in social situations. The same patient showed a severe decisional impairment and emotional deregulation in his real life environment, especially related to social situations. Elliot is described as the prototype of the hi-functioning frontal patient who experiments severe problems in his daily life.

From the point of view of cognitive rehabilitation, if we consider that the traditional protocols used in treatment are centered mainly to protect or recover the basic instrumental cognitive functions, we can understand why, in a clinical or lab setting, superior executive cognitive disabilities are today particularly hard to treat and thus receive a very reduced attention in relation to their dramatic real-life consequences.

From a theoretical point of view, we can try to explain the striking differences in performance and behaviour between lab and life as result of four main failures of the artificial situations to mimic reality: a) choices and decisions are only to be evoked, not to be really performed; b) lack of the normal cascade of events as actions and reactions; c) compressed temporal frame; d) situations are not really presented, but only described through language (Damasio, 1995). Our diagnostic and rehabilitative tools, built to be used in clinical or laboratory settings, fail their goal with executive functions because they cannot adequately reproduce real situations and the perception of the subject to be really *present* in them. Cognitive assessment and rehabilitation of executive functions faces us with the necessity to transfer our work in real life situations or, as a valid alternative, to be able to build artificial environments who can offer to the subject similar conditions and the same sense of presence.

4. The added value of VR in the treatment of dysexecutive problems

Cognitive rehabilitation has to allow patients to recover their planning, executing and controlling skills by implementing sequences of actions and complex behavioural patterns that are requested in everyday life (A. A. Rizzo & J. G. Buckwalter, 1997; A.A. Rizzo & J.G. Buckwalter, 1997): with these conditions, VR can be specifically indicated to reach this goal (Grealy, Johnson, & Rushton, 1999; A.A. Rizzo, 2000). Moreover VR allows to build realistic spatial and temporal scenarios that can be easily used to increase diagnostic sensitivity of standard paper&pencil tests (Pugnetti, 1995, 1998). For example, in the case of early recognition of Alzheimer's disease, VR may be the most efficient method for a systematic screening of subjects (A. A. Rizzo et al., 1998).

Due to the great flexibility of situations and tasks provided during the virtual sessions, considering both the time, difficulty, interest, and emotional engagement, this new technology allows, besides the diagnostic applications (Zhang et al., 2001), to enhance the restorative and compensatory approaches in the rehabilitation process of cognitive functions inside the traditional clinical protocol.

In our opinion, in general cognitive rehabilitation, the added value of VR compared to the traditional treatment can be summarized according to the following points:

- *customization on user's needs*: each virtual environment can be produced in a specific way focusing on the patient's characteristics and demands;

- *possibility to graduate*: each virtual environment can be modified and enriched with more and more difficult and motivating stimuli and tasks. This last issue shall not be underestimated, because many subjects with cognitive dysfunctions show a low level of motivation and compliance about the traditional rehabilitation iter that is usually repetitive and not stimulating;

- *high level of control*: the possibility of controlling the rehabilitation process in its development is very high. This issue allows to professionals to monitor the level of affordability and complexity of the tasks that can be provided to patients;

- *ecological validity*: a virtual environment allows to stimulate in the subjects emotional and cognitive experiences like in the real life. So the tasks executed during the immersion in the VR can induce the patient to reproduce complex cognitive procedures (such as planning and organizing practical patterns of actions, attention shift, etc…) that are similar in all the aspects to the ones used in the situations of everyday life;

- *costs reduction*: rehabilitation with VR can be cheaper than the traditional one, mostly when it comes to the reconstruction of complex scenarios, also of very complex ones (such as presence of more persons in the same time, particular environmental conditions), which avoids the need to leave the rehabilitation office or building.

Nevertheless, when it comes to the specific needs of rehabilitation of dysexecutive symptoms and frontal lobe syndrome, the employment of virtual environments seems to have another fundamental advantage with respect to traditional non-immersive means.

According to Damasio (Damasio, 1995, see 1st par.) diagnostic and rehabilitative tools used in labs and clinics often fail to assess and treat the frontal patients because they operate within artificial situations, which are far from reproducing the real situations. In this view, immersive virtual environments appear to be the best solution to make lab situations become closer to the natural setting in the subject's perception.

For these reasons, in our work we decided not only to use and implement immersive virtual environments, but also to assess very carefully the key variables that support such choice: subjective sense of presence; qualitative evaluation of virtual experiences; usability level.

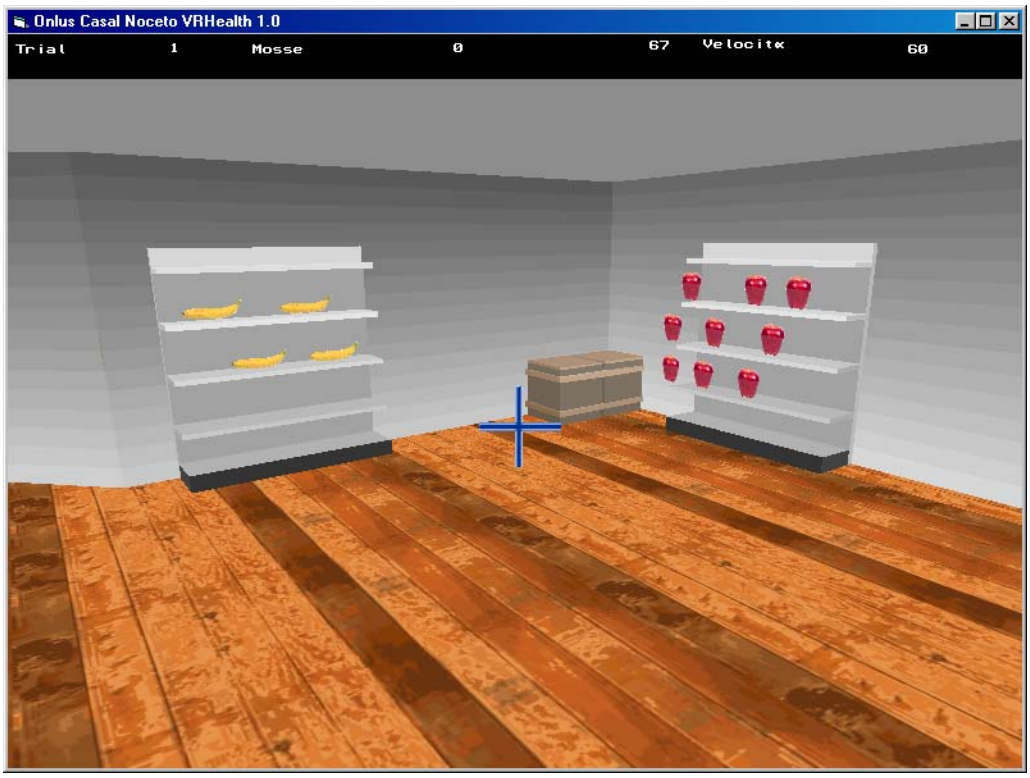
5. A possible VR-based tool for the rehabilitation of executive functions: the V-Store.

In the “Paolo VI Centre of Cognitive Rehabilitation” at Casalnoceto (AL, Italy), the traditional protocol followed in the cognitive rehabilitation has been experimentally integrated with sessions of Virtual Reality.

V-STORE is a virtual environment that consists of a fruit store internal room: the subject (or more correctly his “avatar”, his representation within the virtual world) is set in front of a conveyor belt on which some baskets (from one to three) cross the room. The subjects’ task is to fill up the baskets with pieces of fruit that can be found in four shelves located along the other walls of the room.

At the beginning of each trial, a verbal command is communicated through a loudspeaker, located on the front wall, by which the subject is instructed about what to do: how to fill the baskets and with what kind of fruit. The task has to be completed accurately before the baskets run out of the room on the belt, or else the trial will be repeated from the beginning. It is possible to fix a maximum limit in how many “moves” the subject can execute to solve the trial, forcing him to follow the most efficient and quick strategy.

Figure 1. A screenshot of the first level of V-Store



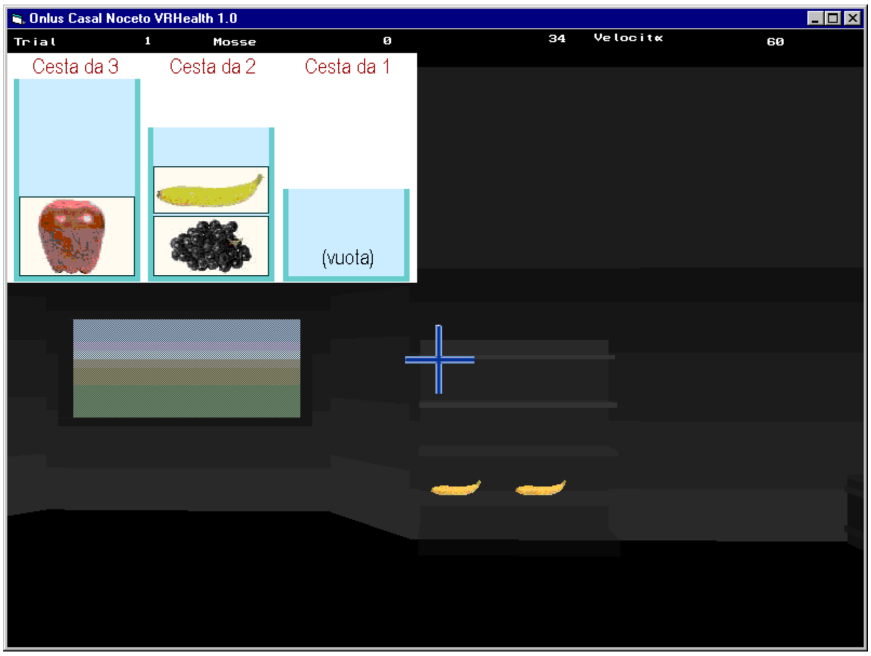
The tasks are ordered according to their complexity, starting from very quick trials that need few fruit moves, up to trials that start with a long and verbally complex command and request special strategies in moving the available fruits from one basket to another. The trials are currently divided in six levels of ten tasks each.

Other elements which are present in the environment are a waste basket, the light switch and a wall telephone, located on the rear wall, through which the subject can receive supplemental orders that integrate the initial verbal command in the most difficult level. The subject can intervene on some additional commands, by which he can stop the belt, end the trial, freeze time.

The supervising examiner can introduce a series of distracting events which increase difficulty and are meant to generate time pressure: room light fainting or progressive dimming, telephone ring, belt speed modification. In these situations, the most interesting focus of performance and rehabilitation consists in the managing steps that the subject will operate and his strategic approach.

For each trial, the system records the following data about the subject's performance for further analysis or research: accuracy, execution time, moves and strategical planning, and furthermore the managing steps taken to face distractors or difficulties, which often constitute the greatest limit for frontal patients.

Figure 2. A screenshot of the last level of V-Store (room lights dimmed)



Ongoing studies in "Paolo VI Centre of Cognitive Rehabilitation" aim at planning, developing and testing a rehabilitation protocol with virtual different virtual tools (see

Table 2) for high-level cognitive dysfunctions that affect patients with brain injures, cerebral diseases, degenerative pathologies and in particular subjects who can be evaluated as “frontal patients” in scientific literature: we also suppose that the developed applications could be useful in a broad spectrum of rehabilitative opportunities.

Table 2. Synthetic description of the V-Store and other tools that ongoing studies are developing in “Paolo VI Centre of Cognitive Rehabilitation” at Casalnoceto (AL, Italy).

Name	*Goal*	*Brief description*
V-Store *Virtual Store*	▪ rehabilitation	Virtual environment (internal store) in which the subject (clinical or experimental) has to solve a series of tasks ordered in six levels of increasing complexity. Tasks are designed to stress executive functions, behavioural control and programming, categorial abstraction, short-term memory and attention. A series of distracting elements are present, aimed to generate time-pressure and to elicit managing strategies. The examiner has full control on all variables, to enhance usability and to increase the number of sessions that a single patient will be administered
V-ToL *Virtual Tower of London*	▪ rehabilitation ▪ diagnosis	A virtual version of the well-known Tower of London Test by Shallice (Shallice, 1982), using the same environment as V-Store. The test is meant to evaluate the executive ability to program behaviors in time. The original paradigm and trial sequence is carefully respected, to grant the clinical and scientific equivalence of results. The task can be used as a one-time assessing test or repeated as a rehabilitative tool (the examiner can intervene on all variables implied).
V-Wcst *Virtual Wisconsin Card Sorting Test*	▪ rehabilitation ▪ diagnosis	A virtual version of the well-known Wisconsin Card Sorting Test (Heaton & Pendleton, 1981), using the same environment as V-Store. The test is meant to evaluate the executive abilities of categorization, abstraction and behavioural flexibility. The original paradigm and trial sequence is carefully respected, to grant the clinical and scientific equivalence of results. The task can be used as a one-time assessing test or repeated as a rehabilitative tool (the examiner can intervene on all variables implied).

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