A Virtual Supermarket to Assess Cognitive Planning

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Abstract: Patients with diffuse or focal cerebral lesions encounter cognitive planning alteration that interferes with social and professional activities. Standard cognitive tests of detection have some difficulties in predicting what occurs in patients’ everyday life and seem inadequate in terms of sensitivity or specificity. Virtual reality offers the capacity to assess patients in situations close to their daily activities, thanks to the safe and controlled progress of the patients in a virtual environment (VE). Moreover, the introduction of gaming factors may improve the motivation of patients.

We present our approach in cognitive planning assessment for patients with Parkinson's disease. We designed a fully textured virtual supermarket (VS) in which the patient can freely move behind a cart and execute precise tasks. During a session, we record all the efficient and inefficient actions of the patient, her/his errors, and her/his regular positions in the VS. We also developed an analysis procedure of all the recorded data. The performances collected among six patients were compared to those of five healthy volunteers in order to validate this approach and to evaluate its sensitivity.

Executive function disorders are difficult to categorize. Many studies emphasize the requirement accurate cognitive assessment and rehabilitation cognitive methods relevant to the patient’s real world. We expect that virtual reality techniques should allow significant progress in the prediction of action planning in everyday life. The ecological characteristics of our environment allow further use for behavioral training.

INTRODUCTION

The cognitive disorders of neurological pathologies constitute a major public health problem, consequently, the detection and the rehabilitation of these deficits must be adequate and occur as early as possible.¹ A major criticism of work carried out to date is that the traditional cognitive tasks are very dissimilar to the everyday situations. These issues are especially important for neurological pathologies in which the cognitive alteration induces an important social and professional impairment, as with Parkinson’s disease (PD).²⁻⁵ This degenerative pathological entity is characterized by an extrapyramidal syndrome combining akinesia, rigidity, tremor, and axial signs. However, PD patients frequently develop cognitive dysfunction even the early stages of the disease.⁶ This impairment predominantly involves executive functions that are largely sustained by the prefrontal cortex and related to deficits in control of attention, planning, capacity to elaborate a strategy, set shifting, and working memory.⁷ Furthermore, among the cognitive functions, planning is omnipresent in everyday life and is the most important component of cognitive PD alteration.⁸ This cognitive process is an executive component which ensures the fitting and space-time scheduling of the various stages necessary to a particular plan of action. Different but complementary models were proposed.⁷,¹⁰ One of the significant concepts introduced here is that of schemas of action.¹ The schema corresponds to an elaborate cognitive representation during various sensori-motor and intellectual experiments of the subject; it is composed of units of articulated circumstantial elements. If the articulation of these units works stereotypically, they remain flexible and able to adapt to the external constraints. The traditional executive tasks do not make it possible to explore such concepts, and they are frequently inefficient in terms of sensitivity or of specificity.⁷,⁸ These tests in particular leave little initiative to the subject. Some ecological paradigms were built to rectify this
situation, but as they are held in real time and in a real environment, this considerably limits their use, especially for patients who are not physically autonomous. The modeling of planning, as presented above and the need for tests with the ecological character contributed to the emergence of new cognitive tests. The scripts of these new tests try to relate the assessment with equivalent daily life behavior. In fact, the test of scripts consists of a sequential and hierarchical organization of actions referring to a particular situation (for example, going shopping). These paradigms, while placing the subject as far as possible in current situations, aim at better understanding the deficits which are specifically expressed in daily activities, and at a better comprehension of the complex interactions of cognitive disturbances that has occurred within these activities. However, without any physical activity, the subjects have to verbally describe what they are supposed to do.

The recent advent of virtual reality technology allows the presentation of scenarios or scripts that are ecologically valid (i.e. very close to daily situations). The technology of the virtual environments has the capacity to create sets of 3D dynamic stimuli, inside which all the behavioral answers can be recorded and measured. In addition, the introduction of the gaming factors into the cognitive evaluation improves the motivation of subjects. It has also been shown that active patient participation is a key factor in successful rehabilitation. Finally, such an environment makes it possible to optimize the training, the generalization, and the transfer of acquisitions toward the real world.

**PROJECT GOALS**

Since we intend to provide indications on the cognitive capacities in everyday life, it seems of higher interest to conceive of diagnostic situations that maintain the characteristics of the real situations while preserving the criteria of standardization necessary to any evaluation. We propose to evaluate planning using a 3D environment built on the model of scripts described above.

**The Tasks and the Environment**

We developed an original paradigm similar to the "shopping list test" in a supermarket, which foresees a series of actions; concretely, the patient should buy a certain number of products. The search for a particular object (for example, a cleaning product) allowed the clinicians to analyze the strategic choices made by the subject and thus the capacities of planning.

We wanted to analyze the visuospatial and temporal aspects of planning. The correct responses and the errors were recorded.

**Target Population**

This methodology was applied first in a pilot study involving both healthy elderly subjects and patients suffering from PD.

The PD patients were referred by a neurologist and selected from out-patients at the Neurology Department of the University Hospital of Caen, France. They were included in the study according to the following inclusion criteria:

- Age ≤ 80 years
- Ability to read and write French, with more than five years of education
- Idiopathic PD, according to the criteria of Gelb
- Only L-DOPA and dopamine agonists allowed as anti-parkinsonian therapy
- Good response to therapy
- Lack of dementia as evaluated by the DSM-IV
- Hachinski modified vascular score of less than two
- No known history of brain or thyroid gland disease, alcoholism, use of psychotropic major agents, or depression as measured by a Montgomery and Asberg Depression Rating Scale score below six

The severity of clinical symptoms (mild to moderate: stage 1 to 2.5) were assessed on dopaminergic medication using the Hoehn and Yahr scale.

The control subjects were included in the study according to the following inclusion criteria: Age ≤ 80 years; ability to read and write French, with more than five years of education; lack of depression and dementia as evaluated by the DSM-IV; Hachinski modified vascular score of less than two; no known history of brain or thyroid gland disease, alcoholism, or use of psy-
chotropic major agents, as evaluated using a clinical examination and a medical questionnaire.

Assessment Tools

The evaluation of global intellectual efficiency was carried out with Mattis’ scale,\(^{21}\) which explores through its sub-scores the following cognitive processes: attention, initiation, capacities of conceptualization, and memory.

The classical exploration of executive processes was done with a validated executive battery that included the Wisconsin Card Sorting Test,\(^{22}\) the Brown-Peterson Modified Paradigm,\(^{23}\) the Stroop test,\(^{24}\) and Verbal Fluency.\(^{25}\)

MATERIALS AND METHODS

Equipment and Software

The system configuration is a Compaq Minitour, Intel Processor 2.4 GHz, 512 MB of RAM, video card GE Force4 MX420 64Mo, and a plug-in to visualize the virtual worlds. Such equipment can be made available in every hospital environment.

The virtual world images are displayed on a large screen monitor. The patient navigates in the world either with the keyboard or with a Wingman Logitech game pad. The patient interacts with the world using the mouse or the game pad.

We used two main software tools to create the 3D virtual exposure environment. We designed the objects, the visual effects, and the virtual worlds with Discreet 3D Studio Max 4. The 3D design was then integrated in a behavior-based interactive 3D development tool, Virtools Dev, which allows the implementation of behaviors through scripts.

The environments are running on PC and can be viewed with the freely downloadable Virtools Web Player (www.virtools.com).

The Virtual Environment

The Virtual Supermarket (VS) was designed to train action planning in PD. It simulates a fully textured medium-size supermarket with multiple display stands for drinks, canned food, salted food, sweet food, cleaning equipment, clothes, stationery and flowers. It also contains refrigerators for milk and dairy products, freezers, four specific stalls for fruits, vegetables, meat, fish, and bread. It also has four check-out stands, a reception point, and a cart (Figures 1 and 2). Some obstacles, such as packs of bottles or cartons, were designed to hinder the advance of the patient in the different paths. They can be removed if the patients feels it is too difficult to move around them. We introduced some characters in the supermarket such as a fish counter clerk, a butcher, check-out operators, and some customers.

The patient enters the supermarket behind the cart and moves freely inside. Her/his first task is to buy a clearly defined list of products, go to the check-out stands, and pay. Other tasks could be defined later.

We let the patient experience the environments from a first person perspective without the intermediary of an avatar. The patient is represented by a 3D frame (a reference point) bound to a camera and the cart. They move together because of a hierarchy link. The collision tests between the patient and the objects in the environments are managed by the cart, which is also bound to be on floor.

The patient navigates in the virtual supermarket using the cursor movement keys or a Wingman Logitech game pad. These devices allow translation and rotation movements.

The patient is free to pick up products by pressing the left mouse button. If they appear in the list defined by the therapist, they are moved to the cart. At the check-out stand, the patients can put the products on the conveyor belt or put them back in the cart by pressing the left mouse button on the belt. Finally, by clicking on the purse, the patient can pay and go to the supermarket’s exit.

Session Protocol

During two preliminary training sessions, the patient learns to move in the virtual supermarket, to recognize the various places, and to pick up objects which are different from those on the therapist’s list.
Then the patient enters the supermarket for a cognitive planning evaluation. Her/his task is to buy a clearly defined list of products, go to the check-out stands, and pay. The instructions related to the task are, at first, written on the screen, and the defined products are shown in the right part of the screen. As the patient progresses through the supermarket, the products...
appear in the cart and disappear from the screen. The instructions related to the check-out area are verbally given before the beginning of the session.

**Recording and Measurement**

For the purpose of further analysis, the system records and measures various parameters while patient experiences the virtual environment. All the patient actions are recorded. If the patient chooses goods that are not on the list, her/his action is recorded as a mistake. The patient can leave the supermarket without buying anything (and thus without paying). The patient can also stay in the supermarket. All these situations are recorded.

We also measured and recorded the duration of the session and the path of each patient.

**RESULTS**

Our preliminary study compared six PD patients (2 females, 4 males) to five control subjects (4 females, 1 male). All the subjects met the inclusion criteria previously defined in this paper. The mean age of each group was 74.0 years (SD = 5.4) for PD patients and 66.6 years (SD = 7.7) for control subjects. Mattis’ mean score was 136.4 (SD = 6.6) for PD patients and 139.8 (SD = 4.1) for controls, which is consistent with a preserved global intellectual function of our patients. All the recorded data (means and standard deviations) are shown in Table 1. Interestingly, all the patients’ performances are lower than the controls data.

In this small group, only the covered distance and the duration of the test are significantly different. The trajectory, shown in the Figures 3 and 4, demonstrates that numerous stops and turning around the same shelves seem to be characteristics of the PD patients.

**DISCUSSION**

Specific alteration of executive function is a well-known trait of PD. However, planning deficit, although often reported in PD (using the tests of Towers, for example), was not as perfectly clarified as the mechanism (i.e. alteration of planning latency or accuracy of shifting processes). The Tower of London, developed by Shallice to assess planning capacities, is a paradigm in which the subject must move colored balls to match a specific arrangement in the minimum number of moves possible. Using this task, Morris showed that PD patients do not make more moves than those required to resolve problems as compared to controls, but show slowness in the initial thinking time (time between the presentation of the problem and

<table>
<thead>
<tr>
<th></th>
<th>PD Patients</th>
<th>Controls</th>
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<tbody>
<tr>
<td></td>
<td>N= 6 (2 F, 4 M)</td>
<td>N= 5 (4 F, 1 M)</td>
</tr>
<tr>
<td>Age</td>
<td>74.0 ± 5.4</td>
<td>66.6 ± 7.7</td>
</tr>
<tr>
<td>Mattis Scale</td>
<td>136.4 ± 6.6</td>
<td>139.8 ± 4.1</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>343.1 ± 113.9 *</td>
<td>224.8 ± 36.4</td>
</tr>
<tr>
<td>Duration (min)</td>
<td>20.4 ± 8.2 *</td>
<td>10.4 ± 1.3</td>
</tr>
<tr>
<td>Stops Number</td>
<td>56.6 ± 32.9</td>
<td>25.4 ± 3.5</td>
</tr>
<tr>
<td>Mean Stop Duration (sec)</td>
<td>13.4 ± 2.3</td>
<td>12.3 ± 2.3</td>
</tr>
<tr>
<td>Time to Pay (sec)</td>
<td>14.6 ± 12.8</td>
<td>5.7 ± 8.1</td>
</tr>
<tr>
<td>Good Actions</td>
<td>11.6 ± 1.5</td>
<td>12.0 ± 0.0</td>
</tr>
<tr>
<td>Intrusions</td>
<td>3.6 ± 3.3</td>
<td>2.0 ± 0.7</td>
</tr>
</tbody>
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*: p < 0.05, significant difference between the two groups, using the non parametric Mann-Whitney test.

Table 1. Means and standard deviations of the recorded data.
the first movement). The authors interpreted these results as a difficulty to elaborate an action plan, a deficit which essentially concerns the anticipation of the optimal solution. Taylor et al. suggested that the principal cognitive deficits in patients with PD occurs in tasks involving "self-directed behavioral planning." However, in a later study involving patients with mild PD, no deficits were found using a three-disk planning problem solving similar in design to the Tower of London test. The fact that patients with mild PD were not impaired in terms of solution accuracy contrasts with the severe impairment observed in these patients on other "frontal lobe" tests. This may suggest that planning deficits remain undetected if the task employed is insufficiently challenging for these patients. These results underline the usefulness and the difficulties of an adequate evaluation of planning abilities.

Our data suggest a partially altered planning function and provides further understanding concerning the mechanism of this deficit. The absence of significant difference with regard to control subjects for the number of correct actions suggests that global access to the semantic knowledge of the script is normal in PD. However, in our study, the introduction of specific measures such as, distance, duration, number of stops (see Table 1), as well as the trajectory record, allow us to precisely identify

Figure 3. Path of a control subject.

Figure 4. Path of a PD Patient.
the planning alteration in PD. Godbout et al. tried to precisely identify these mechanisms using a script generation test. It was found that the patients with PD generate less sub-orderly actions, "minor actions," than super-orderly actions, "major actions." The patients would have difficulties recalling contextual elements and consequently their representations of routine activities would not be as rich and detailed as those of controls. Such difficulties could reflect a SAS (Supervisory Attentional System) deficit which modulates cognitive operations. The increased distance and duration, as well as the inefficient trajectory (see Figure 4) observed in our PD group, are consistent with a slowness of information treatment and with the insufficient use of contextual elements. These results underline spatial and temporal aspects of planning deficits in PD. The trajectory utilized by the patients could also suggest a dysfunction in the switching mechanism necessary to treat in parallel several items of information. Our future analyses using correlations with classical executive tests could help interpret our results.

From a more general point of view, this kind of VE seems to be a useful tool for planning evaluation and rehabilitation. Several teams have already underlined the advantages of this technique, particularly its ability to evaluate the executive functions and attention properties. One of the specific interests of our VE, compared with previous studies, is the strict similarity to the real world. In fact, we took into account the real dimensions of a supermarket, we reproduced the various shelves, and unlike other studies, the subjects can move freely throughout the supermarket. Finally, our principal target population, those with PD, are characterized by a dysfunction in motor symptoms. VR describes the alterations of planning by utilizing a non-clinical point of view, by testing "pure" mental sequences without the interference of motor disability.

CONCLUSION

In accordance with our experience in action planning, and our dissatisfaction with the current tools of evaluation, we decided to design a 3D-supermarket to assess action planning for patients suffering from PD. As with many applications in behavioral neuroscience, we designed a controlled environment that is as life-like as possible. We defined the requirements, the patient tasks, and the assessment tools. Our data suggests a gradual decrease of planning processes in PD as well as an inefficient use of contextual elements; however, these results must be confirmed on a larger group. Furthermore, the criteria of success will be constituted by the following additional points: the facilitated use by the subjects, the adaptability of the software, sensibility superior to that of the usual cognitive tools, and improvement of cognitive deficits after training.

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REFERENCES


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