Computer-Based Post-Stroke Rehabilitation of Prospective Memory☆

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We present a computer-based environment for rehabilitation of prospective memory in stroke survivors. Prospective memory (PM), or remembering to perform actions in the future, is of crucial importance for everyday life. This kind of memory is often impaired in stroke survivors and can interfere with independent living. Fifteen participants were recruited to participate in our study consisting of 10 sessions. The participants were first trained on how to develop visual images in order to remember time- and event-based prospective memory tasks. After the visual imagery training, participants practiced their PM skills using videos, and later in a virtual reality (VR) environment. The results show a significant improvement on PM skills as measured by the CAMPROMPT test, which remained stable 4 weeks after the treatment. VR-based training was well accepted by the participants.

Keywords: Stroke, Prospective memory, Rehabilitation, Computer-based treatment, Visual imagery, Virtual reality

Stroke is the second leading cause of death and a major contributor to disability (Gommans et al., 2003; World Health Organization, 2015). Cognitive impairment plays a crucial role in determining the broader outcomes of a stroke survivor (Barker-Collo et al., 2009; Hochstenbach, Anderson, van Limbeek, & Mulder, 2001). The extent of impairment directly affects aspects of daily functioning (Patel, Coshall, Rudd, & Wolfe, 2002; Zhu et al., 1998), and often necessitates constant care. Customized rehabilitation, performed by trained medical staff, is required but is labor-intensive and expensive (DeJong, Horn, Conroy, Nichols, & Healton, 2005). Neuropsychological research suggests that appropriate cognitive training could improve functioning, remediate core deficits, and positively affect quality of life (Barker-Collo et al., 2009; Gaggioli, Meneghini, Morganti, Alcaniz, & Riva, 2006; Medalia, Aluma, Tryon, & Merriam, 1998; Wolinsky et al., 2006, 2009).

The problem faced in the field of brain injury is two-fold. First, to further neuropsychological research, different types of training need to be applied to large samples of patients (Grealy, Johnson, & Rushton, 1999), requiring significant clinical input and resources. As a result, guidelines used by clinicians to provide specialized care have been criticized as being based more on expert opinion than on empirical evidence (Rohling, Faust, Beverly, & Demakis, 2009). Second, once the ideal training has been determined, it has to be accessible cost effectively to all patients, anytime, anywhere, and at their level and pace. Presently, these goals are not achievable, and rehabilitation research and practice focus on managing disabilities rather than improving cognitive outcomes. Therefore, research on developing effective computer-based cognitive rehabilitation is of high importance.

Stroke survivors and brain-injury patients often have severely impaired prospective memory (Brooks, Rose, Potter, Jayawardena, & Morling, 2004; Mathias & Mansfield, 2005). Prospective memory, or remembering to perform actions in the future, is of crucial importance for everyday life (Ellis & Kvavilashvili, 2000; Titov & Knight, 2000). PM failure can interfere with independent living, as it can result in forgetting to take medication, switch off the stove, or missing doctor's appointments. It is a complex cognitive ability, which requires coordination of multiple cognitive abilities: spatial navigation, retrospective memory, attention and executive functioning (Knight & Titov, 2009).

There is a distinction between event-, time- or activity-based PM (Fish, Wilson, & Manly, 2010; Kvavilashvili & Ellis, 1996). In the case of a time-based task, a certain task needs to be performed at a certain time (e.g. having a dentist's appointment at 3pm). In event-based tasks, a task needs to be performed when a certain event happens (e.g. returning a book to a friend when we see them next). Finally, in an activity-based task, one needs to perform a task after or before performing another task that together could be defined as parts of an activity (e.g. switching off the stove after finishing cooking).

To be able to perform a task in the future, a person needs to know the task (retrieved from the retrospective memory), a level of intention, and a cue. Cues are prompts that help people

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remember the tasks to be performed in the future. Einstein and McDaniel (1990) explain how cues help the process of remembering. When a person perceives a cue, it delivers the information that was previously associated with the cue to the consciousness, and the person remembers the task. Previous research indicates that cues help a person's prospective and retrospective memory as it reinforces their intention to execute a task (Gollwitzer, 1996). A procedure to test PM requires an on-going task in which a person is absorbed, with pre-designated cues appearing randomly, requiring corresponding actions to be performed (Knight, Titov, & Crawford, 2006).

Prospective memory is very difficult to assess using neuropsychological tests as conventional tests consist of simple, abstracted activities divorced from the complexity of real-world tasks. In order to assess PM, it is necessary to obtain information about how a patient functions in everyday life, which is difficult to achieve in laboratory settings. Research shows that scores from neuropsychological tests often cannot be translated to conclusions about the level of impairment and therefore rehabilitation goals because many conventional tests lack ecological validity (i.e. similarity with real life) (Knight & Titov, 2009). It is therefore necessary to replace such tests with tasks that mirror real-word activities (Brooks & Rose, 2003; Burgess et al., 2006; Knight & Titov, 2009). However, assessing patients in real-world situations entails logistic problems and is not achievable in rehabilitation units (Brooks et al., 2004). When real-life tasks are performed in the laboratory settings, they still may have low ecological validity, as visual and auditory distractions are usually minimalized (Knight et al., 2006).

In the last decade, many research projects have used virtual reality (VR) in neuroscience research and therapy (Bohil, Alicea, & Biocca, 2011), ranging from the use of VR for assessing cognitive abilities, over neuro- and motor rehabilitation to psychotherapy, such as treatment of phobias. VR environments are computer-generated environments that simulate real-life situations and allow users to interact with them. They provide rich, multisensory simulations with a high degree of control and rich interaction modalities. They can also have a high level of ecological validity. VR has been used for assessment of PM in patients with traumatic brain injury (TBI) (Knight & Titov, 2009) and stroke patients (Brooks et al., 2004). VR is suited for PM as it supports complex, dynamic environments that require coordination of many cognitive abilities.

Although there has been some research done on how to assess PM, there is very little available on rehabilitation strategies for PM (Shum, Fleming, & Neulinger, 2002; Yip & Man, 2013). Some studies have focused on strengthening retrospective memory with Alzheimer's patients, but using the spaced retrieval technique (Camp, Foss, O'Hanlon, & Stevens, 1996) and errorless learning (Kixmiller, 2002). Sohlberg, White, Evans, and Mateer (1992) reported on a study, which involved a small number of patients with acquired brain injury being involved in repeated practice of tasks over increasing delay periods. This approach requires a lot of practice over a long period, with the increase in delay of 4–8 min. The reported success rate ranged from 40% to 80%, but the gains did not generalize to activities outside the clinic setting (Sohlberg & Mateer, 1989). Another approach reported in (Fleming, Shum, Strong, & Lightbody, 2005) involved an intervention of compensatory type: it focused on increasing awareness of the impaired PM and use of compensatory strategy (a diary). They performed three case studies with small numbers of participants, and although there was a gain, there was a lack of adequate controls. In a follow up study with TBI adults, Shum, Fleming, Gill, Gullo, and Strong (2011) investigated the effects of a compensatory strategy and self-awareness training compared to active controls, and found larger improvement in PM for participants who had compensatory PM training, even though the intervention was short (eight weeks) and of low intensity.

Yip and Man (2013) involved 37 participants with acquired brain injury in 12 sessions of PM training using non-immersive VR. The participants were asked to perform a set of event- and time-based PM tasks in parallel with an ongoing task. The PM training was based on remedial and process approaches. The remedial approach provided repetitive exercise within the VR environment. The process approach, on the other hand, aimed to support multiple facets of PM, and supported encoding of intention, retention, and performance interval and recognition of cues. Participants were given a list of four shopping items they needed to memorize, and their recall was tested before entering the VR environment where they needed to perform the tasks. The VR training showed significant improvement in participants' immediate recall of PM tasks, performance on both time- and event-based tasks as well as ongoing tasks, and a significant improvement in self-efficacy.

Visual imagery has also been studied as an approach to improving memory. It is a technique in which the participant forms a visualization of a given word. The same strategy can also be used to make a visualization of a pair of words, by linking the words and making the visualization as unusual as possible to make it more memorable. Previous work (Lewinsohn, Danaher, & Kikel, 1977) has shown that visual imagery improves retrospective memory. McDaniel and Einstein (1992) showed that PM performance improved when participants were given pictures of targets, or when participants formed mental images of cues.

Potvin, Rouleau, Sénéchal, and Giguère (2011) investigated the effectiveness of visual imagery techniques in PM rehabilitation. They developed training based on visual imagery, which strengthens the cue-action association. Ten TBI patients were trained to form mental images, which associate cues with intended actions in a series of more complex tasks, over ten weeks (one 90-min session per week). In the early sessions, participants were taught how to visualize simple objects presented visually or orally. In a later session, the participants learnt to apply visual imagery in PM and in everyday situations. This experimental group was then compared to a group of 20 TBI patients who received a standard intervention consisting of a short session explaining various compensatory strategies. The participants who were trained in visual imagery improved their performance on the PM experimental tasks and also reported fewer PM failures in everyday life.

Our aim was to develop a computer-based environment for rehabilitation of PM in stroke survivors. We have developed

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