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Augmented Reality Assisted Upper Limb Rehabilitation Following Stroke

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1. Introduction

Stroke is a rapidly developing loss of brain function(s) resulting from lack of blood flow caused by either a blockage, or a hemorrhage (Sims & Muyderman, 2009). Common motor impairments after stroke include muscle weakness, reduced reaction time, loss of joint range of motion and disordered movement organization: hemiparesis or weakness on one side of the body is common. It is widely regarded as a leading cause of disability in the developed world (Adamson et al., 2004). For survivors of stroke, these impairments can severely limit daily activities and participation in social and family environments (Merians et al., 2002; Werner & Kessler, 1996). The upper limb (UL) in particular remains problematic post stroke. Whereas up to 83% of stroke survivors learn to walk again (Skilbeck et al., 1983), it is estimated that only 5 to 20% of stroke survivors attain complete functional recovery of their affected UL (Kwakkel et al., 2003). This may be in part because the high costs of standard therapy mean that treatment frequently ceases once patients are released from acute care and long term outcomes are often poor (Feys et al., 1998; Carter et al., 2006). Another possibility is that it is possible for the patient to learn to use their unaffected arm almost exclusively for most activities of daily living, whereas the patient has no choice but to use both legs for walking (Feys et al., 1998; Kwakkel et al., 1999). Additionally, significant loss of hand function may cause some people to abandon any residual function in that hand through learned non-use (Sterr et al., 2002).

Best practice rehabilitation requires multiple trained personnel up to 30 hours of therapy a week (anon, 2007), but this is seldom achieved and outcomes of conventional therapy are poor (Feys et al., 1998). Evidence suggests that repetitive training of functional UL motor tasks (Van Peppen et al., 2004; Kwakkel et al., 1999; van der Lee, 2001); intensity of practice, and functional relevance of the motor tasks (French et al., 2009; Butefisch et al., 1995) are the critical components of successful UL rehabilitation. Neuroplasticity is the process by which neural circuits in the brain are modified by experience, learning and/or injury (e.g. Nudo, 2003) that allows for motor-relearning and recovery after stroke. A large number of repetitions of the same movement pattern forms the physiological basis of motor learning and is thus an essential component of motor-relearning (Butefisch et al., 1995). Animal studies indicate that as many as 400 to 600 repetitions per day may be required to induce changes in neuroplasticity following stroke (Nudo et al., 1996). But repeated motor activity on its own is not sufficient however to promote recovery: the specificity and functionality of
the repeated task is also an important consideration associated with functional recovery (Buteifisch et al., 1995; Nudo et al., 1996; Plautz et al., 2000).

Subjective well-being is reduced one year post stroke and this is mainly attributed to poor arm function (Wyller et al., 1997). However, improvements in outcomes can be seen up to 3 years post stroke (Stinear et al. 2007), well past the point at which standard rehabilitation therapy stops (Stein et al., 2009). There is, therefore, a clear need for effective UL rehabilitation tools that provides large repetition of functional movements and can be used in a home setting without the constant supervision of a therapist.

2. Robot assisted rehabilitation therapy

From the standpoint of the therapist, the large number of repetitions necessary for effective rehabilitation is very labour intensive. Robot-assisted physiotherapy (e.g. robotic or automated exercise machines) can help in alleviating therapist work load by providing autonomous training where patients can engage in repeated and intense practice of goal-directed tasks (Prange et al., 2006). For example, Krebs et al (2008) describe a 2 DOF robot, the MIT Manus, that trained shoulder and elbow movements in a horizontal plane, although robots can be used for “teaching a trajectory” or “enabling a movement through minimal assistance”, the amount of guidance for maximising recovery is not known (Adamovich, 2009). Robotic-assisted therapy devices can also provide an objective and reliable means of monitoring patient progress, and can be used in conjunction with computer-based augmented or virtual reality environments, leading to improvements in motor function (Fasoli et al., 2003; Krebs et al., 2002; Kwakkel et al., 2008).

Reports indicate that robotic therapy can improve motor control in stroke survivors to a greater extent than conventional therapy and results of clinical trials using these systems to rehabilitate the UL are positive (Prange et al., 2006). However, this is likely to be due primarily to the greater intensity of practice that can be achieved using these devices (Kwakkel et al., 2008).

There is a crucial need to improve the cost-to-benefit ratio of robot-assisted therapy and their effectiveness in rehabilitation of the impaired arm (Johnson et al., 2007). The rehabilitation interventions described in Kwakkel et al. (2008) require patient time on the devices of an average of 48 min per day for 8 weeks. A 6-axis robot can be expected to cost about US$60,000 and deployment (e.g., training, programming, adding tools etc.) may cost another US$200,000. Such a capital item, with a depreciation rate of say 15%, operating 40 h per week, would need to be charged at US$19/h, meaning that robotic arm treatment of one patient’s rehabilitation programme will cost US$800 in capital depreciation alone, regardless of maintenance, running or therapist costs (Kring et al., 2010). Peattie et al. (2009) describe a reaching training robot, based on an arm skate (Fig 1), using a personal computer as the controller. If a low-cost (under US$1000) peripheral device for a personal computer can supply a beneficial therapy, the cost-effectiveness of such therapies would be significantly improved and clinical uptake will be expedited.

3. Virtual reality rehabilitation

Virtual reality (VR) allows the user to interact with a simulated “real” environment via dedicated computer hardware and software (Holden & Dyer, 2002). It potentially provides a
user with a disability a stimulating experience, engaging and motivating to the practice of UL movements as the user manipulates the interface device (Sviestrup, 2004). VR allows the creation and control of dynamic 3-dimensional, ecologically valid stimulus environments within which behavioral response can be recorded and measured, thereby offering clinical assessment and rehabilitation options not available with traditional methods (Schultheis & Rizzo, 2001).

Studies have reported increased participant motivation, enjoyment or perceived improvement in physical ability following the inclusion of VR into stroke rehabilitation (Broeren et al., 2008; Housman et al., 2009; Yavuzer et al., 2008). Importantly, computer games can improve compliance with prescribed rehabilitation exercises (Kwakkel et al., 2008).

Assistive devices may be combined with virtual reality in order to provide a valuable rehabilitation experience for stroke survivors. For example Pyk et al. (2008) describe a combination of data gloves and virtual reality for UL rehabilitation in children with motor deficits.

### 3.1 The Able-X

Industrial Research Ltd (IRL) developed the Able-X for UL rehabilitation of stroke survivors who are able to move their arm against gravity, but have minimal strength or control over their actions (Hijmans et al., 2011). It is a light-weight handlebar (Fig 2) which contains a
motion sensitive game controller (CyWee Z, Taiwan) that interfaces with a PC. The Able-X couples the arms so that the unaffected arm can assist movement of the hemiparetic arm.

A suite of computer games provided a graduated series of physical challenges, from target hitting games, to faster sports games, as well as some casual and puzzle games.

Fig. 2. Against-gravity bilateral exercise device that interacts with computer games.

3.2 Able-X pilot study

3.2.1 Able-X participants

To trial the system fourteen participants with post-stroke UL hemiparesis were recruited: their mean age was 71 years (range 47-85); nine were male, five female; time since stroke one to six years; eight had a stroke in their left hemisphere and six in their right and in nine participants the dominant hand was affected while in five it was the non-dominant.

3.2.2 Able-X assessment, outcome measures and Intervention

Assessments were conducted after enrolment in the study (T0). A 2.5 week sham-intervention was provided which consisted of playing mouse based computer games on a personal computer using their unaffected arm for eight to ten sessions, each lasting at least 45 minutes. Following this, participants were re-assessed (T1). There was a 2 ½ week period where no


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Augmented Reality (AR) is a natural development from virtual reality (VR), which was developed several decades earlier. AR complements VR in many ways. Due to the advantages of the user being able to see both the real and virtual objects simultaneously, AR is far more intuitive, but it's not completely detached from human factors and other restrictions. AR doesn't consume as much time and effort in the applications because it's not required to construct the entire virtual scene and the environment. In this book, several new and emerging application areas of AR are presented and divided into three sections. The first section contains applications in outdoor and mobile AR, such as construction, restoration, security and surveillance. The second section deals with AR in medical, biological, and human bodies. The third and final section contains a number of new and useful applications in daily living and learning.

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