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A changing stroke rehabilitation environment:

Implications for upper limb interventions

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***Abstract*— Functional recovery of the upper limb is poor and as many as 50% of stroke survivors still have impairments at 6 months post stroke, despite rehabilitation efforts. With the move towards early supported discharge and community-based rehabilitation, novel solutions are needed to deliver the amount of quality therapy that is required for optimum recovery. We propose a rehabilitation aid that provides patients with augmented visual feedback of their motor performance during task orientated upper limb therapy with the aim of facilitating motor relearning and maximising patients functional outcomes.**

Keywords- stroke; rehabilitation; upper limb; motor relearning; visual feedback; community-based

I. INTRODUCTION

Stroke is the leading cause of severe adult disability in the developed world [1]. Losses to the sensory and motor pathways in the nervous system manifest as visual, cognitive, speech and motor impairments. A significant proportion of survivors, estimated at 50-75%, are left with impaired arm function [2]; this is particularly disabling as upper limb function is needed for nearly all activities of daily living (ADL), from walking to feeding. Some neuroplasticity, and therefore functional recovery, will occur spontaneously after a stroke but physical therapy stimulates greater recovery of motor functions and encourages learning of new motor strategies. Consequently, at a significant cost to the National Health Service (NHS) each year [3], rehabilitation is attempted to reduce the lasting functional impairments, in order that stoke survivors can live as independent lives as possible. Despite this rehabilitation, functional recovery of the upper limb is particularly poor and as many as 50% of stroke survivors still have impairments at 6 months post stroke [4]. The negative impact impairment can have on a stroke survivor's independence and quality of life makes it a key area of focus for improvement.

Improving upper limb functional outcomes is an essential but difficult challenge. Part of the difficulty is that there is a lack of high quality evidence for many interventions [5]. Current practice would suggest that rehabilitation is most successful when it is of high intensity and repetitive but task-orientated so that it is relevant to ADL. These findings, however, do not fit with the current healthcare model because it is resource intensive. With increasing pressure on the NHS and a move towards early supported discharge and community-based rehabilitation, novel solutions are needed to deliver the amount of quality therapy that is required for optimum recovery. It has been suggested that this changing rehabilitation environment can be managed with technology: to allow intensive yet more independent therapy whilst still maintaining the quality of practice.

In this paper we discuss the current therapy interventions for upper limb stroke and the implications of the move towards rehabilitation in the community. In light of the conclusions drawn, we then describe our proposed design for an upper limb community-based rehabilitation intervention.

II. PRINCIPLES OF UPPER LIMB REHABILITATION AND CURRENT EVIDENCE FOR DIFFERENT INTERVENTIONS

In order to develop an effective therapeutic community-based intervention it is essential that these be underpinned by clinical evidence and the scientific principles of motor relearning.

Key to reducing impairments in the upper limb is to facilitate motor relearning - the process of acquiring or improving performance of a motor skill i.e. everyday activities, such a reaching for a glass. Research has shown that to stimulate relearning, a motor skill requires intensive task orientated practice. To facilitate this relearning, feedback on the performance of the task is required so that progress can be assessed and used to guide subsequent practices. Motor performance is most accurately assessed using biomechanical parameters, to understand how the control and coordination of a sequence of movements combine to form an effective functional action [6].

It could be said that maximising patient outcomes depends on the rehabilitation environment, that is:

- the type of practice available
- the feedback available during the practice
- local environment conditions.

A. *Type of practice*

Clinical evidence to gauge the effectiveness of different treatment approaches for upper limb therapy in stroke is still weak. As such the recently published national clinical guidelines for stroke [5] do not contain any specific recommendations for training strategies for the upper limb. A general recommendation is that stroke rehabilitation should include practice of ADL - everyday functional tasks such as getting dressed or preparing a meal - with evidence that it improves stroke survivors' independence [7]. This reflects motor relearning principles that state that in order to encourage motor relearning, activity needs to be based around meaningful tasks. Upper limb therapy therefore focuses on ADL exercises that require upper limb actions or their main component movements – reach and grasp.

Motor relearning principles would suggest that in order to stimulate motor relearning, task orientated practice is essential and furthermore that for optimal relearning practice needs to be intensive but must remain active and varied.

One would expect that increasing the amount of practice- through increased repetitions or intensity- increases motor relearning. However, clinically neither increasing intensity nor repetitive task training (RTT) are recommended [5]. This decision is based on recent systematic reviews that concluded there is no evidence that increased intensity [8] or RRT [9] significantly improves upper limb function. It would be prudent to note that one review defines intensity as time spent doing exercises and acknowledged that this is a "crude estimate of the actual effort and energy that is spent in performing exercise"[8].

Interestingly these conclusions contradict evidence from constraint induced movement therapy (CIMT), a highly intensive intervention that has shown positive effects on arm motor recovery [10]. Importantly, CIMT aims to increase the intensity of exercise by massed practice - increasing the time spent practicing (often up to 6 hours a day) by restraining the non-affected arm to force repetitive use of the affected arm across many tasks throughout the day. The conclusions by Kwakkel et al [8], are further countered by an interesting finding by Platz et al. [11] that the type of training – task orientated - is more important for arm motor recovery than the therapeutic time spent.

Evidence for the effectiveness of repetitive practice has been shown in results from robot-assisted therapeutic interventions - robotic and electromechanical devices which assist in increasing repetitions and intensity of arm training, through motivation and increased weight support. These have shown very promising results in a research setting, however a recent Cochrane review [12] concluded that when robotic-assisted interventions are compared with conventional therapy, of equivalent intensity and duration, there is no long lasting difference in functional outcomes between groups. This suggests that merely increasing repetitions is not useful and that the type of practice performed during robotic interventions is not yet realistic or varied enough; while practice is intensive with the robot, skills acquired are not transferred to ADL.

It is possibly more useful to take a holistic view of the evidence supporting the most effective type of practice to maximise upper limb functional outcomes. In summary an intervention should be patient-centred in that it should encourage mass practice of functional tasks, so that patients can acquire the skills to be able to perform the functional tasks they need to; so that the exercise always involves some degree of problem solving as mindless repetitive training is unlikely to stimulate motor relearning; and should be of suitably high intensity because amount of practice is related to motor relearning but not to the extent that patients are no longer actively involved in the execution of the exercises.

B. Feedback

In addition to practicing tasks, feedback on the performance of the action is essential for functional recovery. Intrinsic feedback is naturally occurring sensory information – visual, proprioceptive, tactile – on the status of an action. For stroke patients intrinsic feedback can be lacking due to sensory impairments. Providing extrinsic, or augmented, feedback can add to intrinsic feedback and enhance motor relearning. Augmented feedback is from an external source and can provide the patient with knowledge of results (KR) i.e. information on task and goal success, or knowledge of performance (KP) i.e. information on their biomechanical performance during the task. It has been shown that this additional feedback can assist with error detection and active correction of movements and actions, so that patients can progress and improve their performance in subsequent practices.

In current clinical practice, the therapist plays a key role in giving feedback on the performance of a task, although this is often through subjective observation rather than an accurate analysis of the patient's biomechanical movement performance. The therapist analyses each task, determines which component of the task cannot be performed, supports the patient in the practice of those components, building this up into practice of ADL. Commonly feedback is motivational rather than informative [13]. Instrumentation, such as video or mirrors, is often used by therapists as a form of visual feedback and has been found to support functional upper limb recovery [14-15]. However neither method is optimal in stroke as cognitive and self-image issues mean that the patient can be distracted by their appearance.

Recent research into the role of augmented feedback during upper limb rehabilitation has shown positive results. Two systematic reviews [16-17] both concluded that although there is not enough evidence to recommend the best strategy or nature of feedback, overall it gave added value to stroke interventions.

A promising technology within many therapeutic robotic devices that is not fully exploited is the use of the biomechanical data, from sensors built in to these devices, to provide accurate movement feedback to the patient. Feedback from the robotic devices can be instant, and even displayed visually, so that during a single therapy session patients can be motivated by improvements and importantly, automatic constant monitoring by the devices ensures the therapy can be accurately tuned to the patient's needs [18].

Recent work by Macdonald et al.[19] has lead to the development an innovative method of visually representing biomechanical data, via motion capture technology, that allows those without a biomechanical background – both therapists and patients- to access and interpret data. Furthermore, their findings suggested that visually displaying the data could be used to enhance user understanding of the biomechanics of ADL, which could facilitate motor relearning.

To summarise, in order to maximise outcomes, information given as feedback needs to be as accurate as possible. While encouragement motivates patients to continue towards their goals, informative augmented feedback is essential in order that attention and additional practice can be directed to the part of the action that needs to be improved. Biomechanics provides the accurate basis for understanding movement performance and with new technology there is the potential for it to be incorporated into clinical use to help communicate, through simple visualisations, the therapist's verbal explanation of movement control and coordination problems.

C. Environment

In order for task practice to be meaningful, the practice environment needs to be as real-life like as possible: not only to stimulate motor relearning but to also encourage transfer of the tasks that are learnt into ADL.

The physical environment should give stroke survivors every opportunity to practice activities. Research has shown that in hospital, patients may only use their affected limb during their therapy sessions and that time spent concentrating on the upper limb can be as little as 10 minutes per day [20]. Outpatient rehabilitation is seen as less-intensive, usually with reduced therapy sessions on offer, but it could be argued that patients are in a more stimulating environment which may perhaps result in more practice and transferred learning. In fact a Cochrane review found that home or community-based therapy improves ADL scores [21].

In an attempt to enrich the clinical environment, game consoles such as the Wii or Kinect are being used within stroke wards. These are good at providing motivation to practice but the games haven't been designed to have therapeutic value. Most are not appropriate for stroke patients as they are too fast or complex and although it is advantageous to a degree that patients are exercising their affected limb, the focus is on movement outcome rather than quality of movement or relearning.

Recent experimental interventions have looked at the impact of using of virtual reality (VR) during upper limb rehabilitation [22-23]. VR interventions can be used to enrich the practice environment by facilitating practice of a wide range of tasks and scenarios. They have the advantage of being able to almost instantly vary the environmental surroundings e.g. virtual objects, which allows the tasks to be set to complement the stage of recovery and impairment of the user. VR can also help to keep the patient engaged. High quality evidence in this area is lacking however, a recent systematic review [16] has shown these early trials to be very promising.

In review, to maximise motor relearning the patient needs to be in an active learning environment that offers an as real-life like environment as possible to facilitate the transfer of skills practiced to real-life situations. More recently there has been an increase in VR and gaming being used in stroke rehabilitation. While these engage the patient, it is important that they have a therapeutic goal - focusing on improving quality of movements- to enhance motor recovery.

III. COMMUNITY-BASED REHABILITATION: IMPLICATIONS FOR INTERVENTIONS

Whilst there is promising research into many different upper limb training strategies, few of these interventions have had sufficient evaluation for a conclusion to be reached about their effectiveness in a routine clinical or community-based setting, with the exception of ADL training.

What could be stated is that with a move towards early supported discharge, some of the more promising interventions discussed in the previous section are unlikely to be suitable for community-based rehabilitation. While CIMT is shown to be effective, the intervention is also tiring and time-consuming, which would raise major resource challenges. Similarly robotic devices are prohibitively expensive and at this stage not portable enough for a community-based setting. Virtual reality based therapies have the best potential, if they can remain portable and cost effective, and with the need for high quality research should be an area to focus on.

Despite the current unsuitability of most of these interventions for a community-based rehabilitation setting, what can be taken forward and incorporated into new designs are the underlying principles of skill acquisition which make them particularly effective: challenging, varied and active, task-specific massed practice.

Finally, it is important to consider the implications for the patients that a move to community rehabilitation could have. It can be expected that if patients leave hospital sooner, they will have received less rehabilitation and so may be less independent, due to remaining functional impairments, and therefore require more assistance. Research has shown that patients in the community often want the same amount of therapy as when an inpatient [24]. With a lack of resources to make that possible, new interventions may need to have an added focus on teaching patients so that they have a better understanding of their own rehabilitation to allow quality independent practice out with their therapy sessions.

IV. PROPOSED DESIGN OF COMMUNITY-BASED UPPER LIMB INTERVENTION

To manage the change of rehabilitation to a community environment we propose to develop an novel intervention that provides stroke patients with task orientated practice coupled with augmented visual feedback. The hypothesis is that providing the patient with augmented visual feedback, highlighting the success of their movements and the quality of those movements, during their therapy sessions can motor relearning. Building upon innovative work by Macdonald et al., [19] the augmented visual feedback will be achieved through the visualisation of biomechanical data captured from small, inexpensive motion sensors attached to the upper limb and trunk.

The intervention will enrich task-orientated practice, focusing on ADL exercises that require upper limb actions or their main component movements – reach and grasp. The intervention will be patient specific; by using the technology the task or environment can be altered to a patient's needs based on precise feedback of biomechanical data. Furthermore, there will be a pool of exercises to work from and the patient will practice those actions, or components, of a task they cannot yet perform correctly. Similarly, exercises will be able to be graded according to difficulty so that patients are constantly challenged to improve their performance. The tasks will encourage mass practice: by altering the environmental context of tasks the exercise will always involve some degree of problem solving. This should also ensure the tasks remain challenging and also help sustain the patient's motivation.

The visual feedback will be accurate and focused feedback to promote a better understanding of correct movement patterns and of when movements are compensatory. The visualizations will also be simple and clear, particularly important during early training to remove distractions for stroke patients. The visualisations will allow patients to see the orientation of their joints and coordination of their limb segments to enable self-correction, facilitating motor relearning and allowing patients to take a more active role in their therapy. Feedback of KR will provide the patient with information on the success of the individual tasks i.e. time taken, and their progress towards both short-term and long-term goals. Feedback of KP will inform patients about the control and coordination of their upper limb segments and trunk and the quality of their movements i.e. smoothness, accuracy. It will also highlight any compensatory movements.

To assess the effectiveness of visual feedback as part of community-based upper limb stroke rehabilitation we will carry out a pilot randomised controlled trial. This study will compare current standard therapy against additional upper limb therapy, both with and without visual feedback. Additional therapy will be in the form of twice weekly 1 hour sessions for six weeks. Adults within 3 months of stroke onset and with upper limb impairments will be recruited at discharge from acute stroke wards across NHS Lanarkshire.

V. CONCLUSIONS

There are many different interventions for training the upper limb after stroke, however there is still a lack of consensus over which are the most effective. Further to this, few of those that have shown promise clinically are designed for or have been assessed in a community rehabilitation setting. Developed on the basis of key elements of the current most effective training strategies, it is hoped that the proposed intervention of task-orientated therapy plus visual feedback will help maximise stroke patient's functional outcomes.

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