Neurogame Therapy as an Upper Extremity Home Program for Persons After Stroke: A Preliminary Mixed Methods Investigation

Elena V. Donoso Brown

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Reading Committee:

Sarah Westcott McCoy, Chair

Deborah Kartin

Brian Dudgeon

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Abstract

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Elena V. Donoso Brown

Chair of the Supervisory Committee:
Sarah Westcott McCoy, Professor
Department of Rehabilitation Medicine

This preliminary study was designed to evaluate the effectiveness and acceptability of Neurogame Therapy (NGT), an innovative application of surface electromyography (sEMG) with a computer game, as a home program for persons after stroke. A concurrent mixed methods design was used. A repeated measures design tested the quantitative outcomes such as sEMG, kinematics, and activity measures including the Wolf Motor Function Test and the Chedoke Arm and Hand Activity Inventory. Nested one-on-one interviews were completed to gather information on home exercise programs in general, functional use of the upper extremity, and the acceptability of NGT. Nine participants completed the quantitative portion of the study and ten completed the qualitative portion. A statistically significant change was found across the intervention period on one of the surface electromyography outcomes, however no changes were found in kinematic or activity outcomes. The qualitative interviews provided in depth

information on upper extremity functional use in daily activities and home programs, as well as, information on the acceptability of NGT. Most participants found NGT to be motivating and while most reported no dramatic changes in their upper extremity use, some did report small changes in movement of the affected limb or an increased awareness and desire to use the limb. Participants also identified ways to improve NGT including more time with the system and increased clarity in the interface. The combined results suggest that NGT requires further study and may benefit from the inclusion of a functional activity component that would assist in generalizing changes at the sEMG level to the functional level. This preliminary investigation suggests that NGT is motivating for adults after stroke and acts primarily at the level of sEMG, at this time. Future studies could investigate: (1) adding a functional activity component to the program (2) the use of NGT with persons in the acute phase of stroke recovery and (3) the nature of home exercise from the perspective of therapists and caregiver.

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DEDICATION

This work is dedicated in loving memory of
Anamcara Brown, Theo Brown, and Arthur Moelaart.
Thanks for watching over me. This is for you

CHAPTER 1

RESEARCH METHODS FOR IMPROVING UPPER EXTREMITY REHABILITATION AFTER STROKE

The World Health Organization estimates 15 million people worldwide experience stroke each year (World Health Organization, 2004). In the United States, stroke is the leading cause of long-term disability with over 1.1 million stroke survivors needing assistance with activities of daily living (Centers for Disease Control, 2009). In addition, stroke care has a substantial economic impact with 40.9 billion dollars in direct and indirect costs each year in the United States (Roger et al., 2011). Therefore, reducing stroke related disability is a key focus of rehabilitation research. Upper extremity impairment that follows stroke can significantly effect quality of life (Franceschini, La Porta, Agosti, & Massucci, 2010). This makes rehabilitation research on interventions to improve upper extremity outcomes for persons after stroke critical.

Upper extremity rehabilitation is a complex phenomenon that requires careful evaluation. When addressing upper extremity rehabilitation after stroke researchers will find two separate yet important sets of questions that need to be answered. One set of questions will aim to determine the effect of a particular intervention and focus mainly on outcomes that can be quantified (Grembowski, 2001). The other set of questions describes and explains certain experiences, events, or behaviors that influence interventions or how they are used (Grembowski, 2001). These types of questions are often considered procedural or implementation questions. In order to answer outcome and procedural questions a variety of research methods are used.

Research methods can be categorized as being primarily quantitative (for outcome questions) or primarily qualitative (for procedural or process questions). In this chapter a brief overview of the quantitative and qualitative research paradigms will be described. Furthermore, a sampling of current research on upper extremity intervention will be used to exemplify the methods employed in answering outcome and procedural questions. Finally, the use of both qualitative and quantitative methods (also known as mixed methods) will be discussed as a strategy to address both outcome and procedural questions relevant to the development and testing of upper extremity interventions.

Quantitative Research Methods

Quantitative methods aim to discover an objective rule that can be applied in multiple situations (Kielhofner, 2006). These methods utilize controlled environments and hypothesis testing as a means to identify the objective rule. For example, in a study of an upper extremity intervention, the hypothesis may be that the use of an intervention three times a week will lead to improved upper extremity function. Using designated outcome measures this hypothesis would be tested and either found to be supported or not supported by the data resulting from the study. Quantitative research methods intend to create a controlled environment in which the researcher can be more certain that their findings are a result of their intervention and not outside factors (Kielhofner, 2006). While this tightly controlled environment provides strong internal validity allowing one to be more certain of the effect of the intervention, it can decrease the external validity making the findings more difficult to generalize to the entire population of interest. Given the philosophical underpinnings of the quantitative tradition, it would seem that this method is appropriate for answering questions related to efficacy or effectiveness. Efficacy is the degree to which a program works in a controlled setting. Effectiveness, however, is the degree to which a program works as intended in a real world setting. Some of the quantitative methods utilized in upper extremity stroke research include randomized controlled trials, crossover designs, single group pre/post testing, and single group repeated measures. These methods and examples of them will be discussed in conjunction with outcome focused rehabilitation research.

Qualitative Research Methods

While quantitative research methods aim to discover rules that hold true across multiple situations, qualitative methods were developed out of a different philosophical understanding of the world. Qualitative philosophy posits that each individual constructs their own reality and researchers in the qualitative tradition seek to enter an individual's or group's understanding of a phenomenon while in their natural setting (Creswell, 1998). There are several qualitative theoretical perspectives (e.g. phenomenological, ethnography, qualitative description) that can be used to conduct research on a variety of questions (Creswell, 1998; Sandelowski, 2010). When looking at the use of qualitative research methods in intervention evaluation, Grembowski (2001) suggests that this perspective can be used to understand the meaning, context, and processes of an intervention, as well as identify potential unintended consequences or moderating factors. Qualitative research methods include a variety of research tools to generate data that are different from those used in quantitative research methodology. Some of these tools include, one-on-one interviews, focus groups, participant observation, and artifact collection (Kielhofner, 2006). These qualitative methods are used more infrequently in the current rehabilitation research literature on upper extremity intervention after stroke, potentially due to the rise of evidence-based practice that places a premium on measured outcomes research (Stolberg, Norman, & Trop, 2004; Sullivan, 2011).

Outcomes Rehabilitation Research

Rehabilitation interventions for the upper extremity after stroke are complex and require rigorous evaluation in order to determine their clinical utility and effectiveness. Researchers, when aiming to assess effectiveness, typically utilize research designs and strategies from the quantitative tradition described above. This is because the quantitative tradition strives to demonstrate a causal relationship between the intervention and the outcome, by controlling for outside variables (Grembowski, 2001; Stolberg et al., 2004). The concept of being able to attribute the outcome of a study to its intervention is known as internal validity (Grembowski, 2001; Portney & Watkins, 2009). Researchers using quantitative research designs aim to minimize threats to internal validity, although no single design can rule out all threats (Grembowski, 2001). Figure 1 illustrates some study designs used in upper extremity intervention research after stroke by degree of internal validity. In the next section, examples from the literature will demonstrate how quantitative methods are used in outcome rehabilitation research to demonstrate the effectiveness of upper extremity interventions.

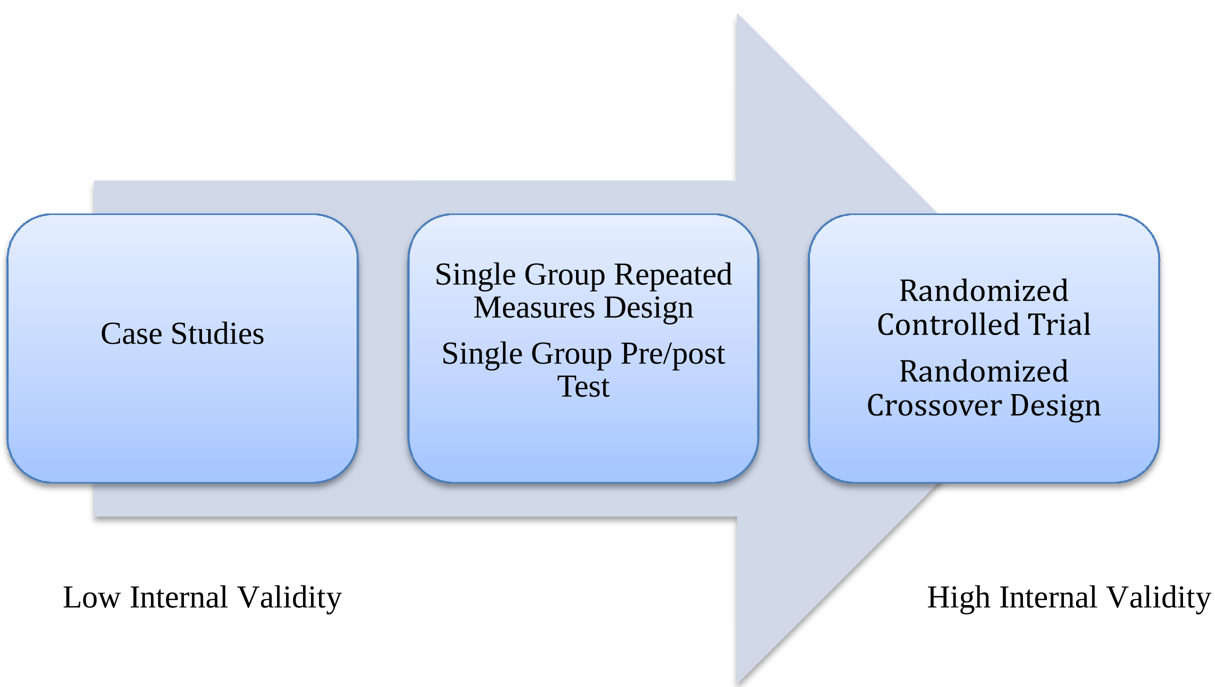

Figure 1. Types of quantitative designs by degree of internal validity

Source: This figure is adapted from Grembowski, D. *The Practice of Health Program Evaluation* Thousand Oaks, CA: Sage Publications; 2001:70

Quantitative Research Designs

When looking at systematic reviews of upper extremity interventions it is clear that the randomized controlled trial is being used more often in upper extremity intervention studies (Coupar, Pollock, van Wijck, Morris, & Langhorne, 2010; Meilink, Hemmen, Seelen, & Kwakkel, 2008; Sirtori, Corbetta, Moja, & Gatti, 2009). A randomized controlled trial is considered the gold standard of research designs (Kroll, Neri, & Miller, 2005; Stolberg et al., 2004). In this study design, researchers aim to control for bias by randomizing participants into two groups. One group receives the intervention and the other receives either no intervention or an active intervention. In a review by Meilink and colleagues (2008) examined electromyography-triggered neuromuscular stimulation of the wrist, out of the eight randomized controlled trials two provided no intervention, while the remaining either gave conventional therapy or some variant of electrical stimulation. Randomization provides researchers with protection from many threats to the internal validity, but not all. The primary threat to internal validity in this type of design is attrition (Grembowski, 2001; Stolberg et al., 2004). If there is a large rate of attrition (i.e., dropping out) either from the control or intervention group the difference seen at the end of the intervention could be because of who left the study and not the intervention (Grembowski, 2001). However, there are statistical ways to manage attrition, such as intention to treat analysis (Grembowski, 2001; Portney & Watkins, 2009).

While randomized controlled trials are considered the gold standard in quantitative research, there are some reasons that researchers do not always use this method including high costs and population access (Mawson & Mountain, 2011). In rehabilitation research, there are additional challenges to utilizing the randomized controlled. One challenge cited by Tonelli

(2010) is that randomized controlled trials provide knowledge based upon group analysis. This provides one type of knowledge however there remains a gap between the information gleaned in randomized controlled trials and the individual patient. In addition, rehabilitation research often requires that interventions work on multiple levels (i.e. body function/structure, activity, and participation) requiring a variety of research methods in a developmental sequence to address the complex nature of the intervention (Whyte & Barrett, 2012). Due to these barriers researchers may use a variety of other quantitative designs. These include crossover design, single group repeated measures, pre/post treatment design, and case studies.

Crossover designs are similar to randomized controlled trials because they also use two groups and persons can be randomized to these groups. The primary distinction between these designs is that in a crossover design after a certain period of time the experimental group and the control group switch places (Kielhofner, 2006). If randomized the crossover nature of this design reduces the threats to internal validity, however there continue to be concerns related to attrition and carryover effects (Kielhofner, 2006). Carryover effects are when the first group to experience the intervention has long lasting effects and this carryover minimizes the effect seen when the second group experiences the intervention. A crossover design was used for the testing of the constraint induced movement therapy. Wolf and colleagues (2010) used this design not only to investigate the efficacy of training but also to examine the differences between early or delayed treatment and provided as treatment to each group. In this study, the crossover occurred after one year from initial enrollment (Wolf et al., 2010). While the long length of delay between the crossover may not eliminate the concern of carryover effects, it does provide time for results to diminish in the first experimental group prior to the second group receiving treatment.

The outcome literature on upper extremity stroke rehabilitation also contains several single group designs. Single group pre/post designs have an increased number of threats to internal validity compared to a randomized controlled trial and crossover designs. Specifically threats related to history, maturation, testing, instrumentation, and regression to the mean (Grembowski, 2001). Descriptions of these threats are presented in Table 1. Nevertheless, this type of design is commonly used in pilot or preliminary studies of upper extremity interventions after stroke (Timmermans et al., 2010; Yong Joo et al., 2010). Yong Joo and colleagues (2010) completed a feasibility study examining the use of the Wii™ as a form of upper extremity rehabilitation and utilized this design. While there were small improvements seen on quantitative outcome measures (Yong Joo et al., 2010), further research will be needed in order to ensure that this intervention approach is effective.

Table 1

Common Threats to Internal Validity

Threat	Description
History	An event external to the person occurs (e.g. read about and do an upper extremity exercise program for persons after stroke in the newspaper)
Maturation	An event internal to the person occurs (e.g. spontaneous motor recovery)
Testing	Pretesting could influence outcome (e.g. persons realize that they could do more with their upper extremity that previously thought and use it more)
Instrumentation	Changing the measurement instrument or who administers the instrument
Regression	If participant are selected because of extreme scores, it often occurs that these extreme score move closer to the average next time they are tested

Source: This table is adapted from Grembowski, D. *The Practice of Health Program Evaluation* Thousand Oaks, CA: Sage Publications; 2001:79

A repeated measures design is similar to a pre/post test design, as it only uses one group, but it has slightly fewer threats to internal validity. This design faces mostly threats to history, instrumentation, and attrition (Grembowski, 2001). Wallace and colleagues (2010) used a single group repeated measures design to study an intervention that standardized the intensity of upper limb treatment for persons after stroke. In this study the researchers used a baseline phase, intervention phase, and a follow-up phase (Wallace et al., 2010). During the baseline phase measurements were taken twice prior to the intervention. This allowed the researchers to establish that the participants' performance was stable over time, prior to the intervention, reducing the threat of maturation. This type of experimental design allows each individual to act as their own control, helping to reduce some other threats to internal validity, such as regression to the mean and selection bias.

Finally, it should be noted that as the study of interventions for upper extremity intervention after stroke has continued to expand, more case studies that demonstrate feasibility of a particular intervention are found in the literature (Burdea et al., 2011; Hardy et al., 2010; Hermann et al., 2010; Mawson & Mountain, 2011). For example, two studies related to technology-based interventions utilized case studies to demonstrate the potential of new interventions (Burdea et al., 2011; Mawson & Mountain, 2011). Case studies, while they can provide interesting information on interventions that are in development, have many threats to internal validity and cannot be generalized to a larger population. Nevertheless, they provide insight into the future direction of therapeutic intervention and can potentially demonstrate a proof of concept.

Quantitative research methods such as randomized controlled trials, crossover, pre/post test, and repeated measures designs are typically used in outcomes research. Each quantitative approach varies in the degree to which it is vulnerable to threats of internal validity. While efficacy and effectiveness questions addressed in outcome research are important, procedural questions allow researcher to assess how the intervention works and who may benefit from an intervention. As Mant states "The paradox of the clinical trial is that it is the best way to assess whether an intervention works, but arguably the worst way to assess who will benefit from it" (1999, p. 744).

Procedural Rehabilitation Research

Rehabilitation research that focuses on outcomes has a limited scope. This singular focus on effectiveness dictates a focused approach to answering outcome questions utilizing primarily quantitative methods. In contrast, procedural questions about intervention implementation are much broader and can be answered through both quantitative and qualitative approaches. According to Grembowski (2001), implementation or procedural research has two primary purposes (1) to describe what is occurring in a particular intervention and (2) to explain a particular occurrence in an intervention. A second consideration for procedural research questions is the timing of data collection (Grembowski, 2001). Data can be collected either in a cross-sectional manner, looking at only one time point, or longitudinally comparing more than one point in time. Table 2 describes how the purpose and the timing come together to create four primary types of procedural research questions (Grembowski, 2001). In upper extremity rehabilitation research several studies have addressed procedural research questions in an attempt to either describe or explain what occurred during a particular intervention. In this section, examples of procedural questions answered using, quantitative and qualitative methods will be described.

Table 2

Types of Procedural Research Questions

Timing of Data Collection	Purpose of Research Question	
	Descriptive	Explanatory
Cross-Sectional	Describe the intervention events activities, or behaviors at one point in time.	Compare the intervention events, activities, or behaviors at one point in time.
Longitudinal	Describe the intervention events, activities, or behaviors at two or more points in time	Compare the intervention events, activities, or behaviors at two or more points in time

Note: This table is adapted from Grembowski, D. *The Practice of Health Program Evaluation* Thousand Oaks, CA: Sage Publications; 2001:145

A handful of studies aimed to assess procedural questions in conjunction with their outcome studies using quantitative methods. For example, when assessing the effectiveness of using the Wii™ with persons after stroke in a pre/post quantitative design, Yong Joo and colleagues (2010) utilized a two-part questionnaire to describe the participants' thoughts on the intervention. The first part was given prior to the intervention to assess the previous experiences of the participants and whether or not they would think of computer gaming as a pastime or a treatment. The second part asked about how enjoyable the intervention was and if they would recommend this training. While the authors did not report any validation of the questionnaire they developed, the use of this questionnaire is a demonstration of a descriptive longitudinal procedural research question, in which the authors were trying to describe the experience of the participants.

A descriptive cross-sectional approach was used when assessing the usability of an upper extremity training system (Timmermans et al., 2010). In this comprehensive and rigorous preliminary study participants were asked to complete The Computer-System-Usability-Questionnaire and the Usefulness-Satisfaction-and-Ease-of-Use-Questionnaire at one point early in the intervention phase (Timmermans et al., 2010). This information was used to complement the results of the repeated measures design. Both of these studies (Timmermans et al., 2010; Yong Joo et al., 2010) utilized additional quantitative methods to answer procedural questions that aimed to describe the experiences of their respective interventions.

Another example that utilizes quantitative data to answer a procedural question is through secondary data analysis of a completed project. Harris, Eng, Miller, and Dawson (2010) completed a randomized controlled trial to assess the effectiveness of an inpatient exercise program. Although they found positive results from the intervention, they wished to explain if these results were affected by the presence of a caregiver or support person. Harris and colleagues (2010) appropriately used multivariate regression to determine the value of having a caregiver or support person. Through this analysis it was found that having a caregiver or support person present did influence the effectiveness of the intervention. This example illustrates an explanatory cross-sectional approach because it compares the results of two groups of persons, which experienced the intervention at one point in time to explain a piece of the intervention outcome.

In addition to secondary data analysis, survey methods have also been used to analyze aspects of upper extremity stroke care. Gustafsson and colleagues (2010) recently described the education provided to patients and their families regarding management of the hemiparetic upper limb. In this descriptive cross sectional study, a study specific tool was piloted and used to collect data from occupational therapists. They found that information about upper limb management is often provided early in the rehabilitation process and that a majority of education is directed toward the patient (Gustafsson et al., 2010). This information, while not addressing the effectiveness of education, provides a useful description of how educational practices for upper extremity management occur in Australia. Survey approaches have also been used to identify areas of upper extremity training that are most valued by persons after stroke (Timmermans et al., 2009).

While many persons have utilized purely quantitative methods to assess procedural questions others have implemented the qualitative approach to understand more about the recovery process for persons after stroke experience. For example, a rigorously conducted qualitative study (Barker & Brauer, 2005), answered a descriptive cross-sectional question that aimed to depict the experience of upper extremity recovery from the perspective of persons after stroke and their caregivers. In this study, the researcher based their exploration in grounded theory, a theoretical perspective that typically utilizes data that are gathered to generate theory (2005). The researchers utilized three focus groups and two semi-structured interviews to collect data on the perspectives of persons after stroke and their caregivers on upper extremity recovery. It was found that a core principle that defined upper extremity recovery after stroke was "keeping the door open" (Barker & Brauer, 2005, p. 1217). This was characterized in statements such as 'Even years later things are still changing as long as you haven't accepted this is all over' (Barker & Brauer, 2005, p. 1217). In addition to this core principle, four defining processes used to maximize stroke recovery were identified: (1) hanging in there, (2) drawing on support, (3) getting going and keeping going with exercise, and (4) finding out how to keep moving ahead (Barker & Brauer, 2005). The strategies identified in each of these sections provide beneficial information to clinicians and researchers about the understanding of stroke recovery and intervention from those persons experiencing it first hand.

Procedural questions have a variety of methods that can be used to answer them, both quantitative and qualitative. While looking at quantitative and qualitative methods, it may appear that the two philosophical backgrounds have far too many differences to be used together. On the contrary, in rehabilitation research efforts have been made to systematically bring these two schools of methodological thought together in a research approach known as mixed methods (Kroll et al., 2005).

Mixed Methods Rehabilitation Research

The importance of the use of mixed methods research methods is highlighted in an article by Kroll and colleagues (2005) who propose that as inpatient length of stay decreases the more the rehabilitation occurs in persons' actual living environments. The randomized controlled trial, while the gold standard for testing effectiveness, does not address these real living environments and in fact attempts to minimize their impact (Kroll et al., 2005). Therefore, the use of both quantitative and qualitative measures in combination may provide a robust mechanism to look at effectiveness while also uncovering how participants experience the rehabilitation process.

Mixed methods approaches require careful planning and an understanding of the value of both quantitative and qualitative research methodologies. Kroll and colleagues (2005) outline two primary strategies for utilizing mixed methods. One strategy is to use quantitative and qualitative methods in a sequential order each one informing the other. For example, one could conceive that the qualitative study by Barker and Brauer (2005) would inform the development of a comprehensive upper extremity outpatient intervention titled "Keeping the door open." This intervention would then be tested using the most appropriate and feasible quantitative method to assess effectiveness. Conversely, the study completed by Harris and colleagues (2010) quantitatively identified that caregiver support made a difference in the outcome and use of an upper extremity exercise program. These authors used a quantitative method with caregiver support being either present or absent, because of this very little is known about what type of support was being given. A follow-up qualitative study could expand on these results and potentially demonstrate some ways that caregivers provide exercise support to persons after stroke. The second strategy for implementing mixed methods is to use both qualitative and quantitative methods concurrently. This strategy requires the use of quantitative and qualitative approaches at the same time to answer different, yet parallel questions. These two strategies to using mixed methods provide a structure that is necessary for this type of research.

While sequential strategies to mixed methods have been particularly useful in the development of measurement tools (Barreca et al., 2004; Hammel et al., 2008) very few studies exploring intervention effectiveness have implemented the concurrent mixed methods approach. Recently, a case study done by Mawson and Mountain (2011), described the use of qualitative methods as part of a feasibility study testing a monitoring system for functional movement. In this study participants completed quantitative measures before and after use of the system as well as a qualitative interview after the intervention in order to determine usability. There are several advantages to the use of concurrent mixed methods in rehabilitation research related to the upper extremity. One of the primary advantages is being able to answer both outcome and procedural research questions. While this could be done in a purely quantitative manner (i.e. use secondary data analysis), the use of qualitative methods has the potential to provide a deeper understanding of the experience of an intervention than through quantitative analysis alone. In order to demonstrate further the value of concurrent mixed methods, a proposed study will explore and describe the advantages and challenges.

Recently, preliminary work has been done to develop an intervention that uses surface electromyography to control a commercially available videogame, now known as Neurogame Therapy. This intervention has been pilot tested with children with cerebral palsy as well as four adults with acquired brain injury. The pilot testing demonstrated proof of concept, but further studies are necessary to determine the potential this home-based intervention has to improve upper extremity recovery in persons after stroke. In order to evaluate this home program, a mixed methods study design was selected to address two primary aims. The first aim was to evaluate the use of this game therapy intervention in the home to improve upper extremity motor performance in adults with chronic impairment after stroke. The second aim was to explore the nature of home exercise programs and also determine the acceptability of the program, as well as identify supports and barriers related to the use of this game therapy intervention in the home for persons with chronically impaired upper extremities after stroke. It is evident that these two questions are different in nature with the first focusing on effectiveness (outcomes) and the second focusing on the experience of the intervention (procedural).

In order to answer each of these questions strategies from quantitative and qualitative research paradigms were used. To address the first aim and assess the effectiveness of the intervention a quantitative research design was used, specifically a single group repeated measures design. This design was selected due to the preliminary nature of this research. In addition, this design, as stated previously, has fewer threats to internal validity than others secondary to it utilizing each individual as their own control. Additionally, the hetreogenous nature of this population would make it challenging to have experimental and control groups that were well matched. To assess outcomes at the body structure and function level, surface EMG and kinematic data were collected. EMG data assessed the amount of independent activation in the targeted muscle groups in order to demonstrate if participants had increased motor control as a result of the intervention. Kinematic data were collected from a reaching task on temporal-spatial measures of reach efficiency. At the activity level, the Wolf Motor Function Test (WMFT) and the Chedoke Arm and Hand Activity Inventory (CAHAI) were used to assess arm and hand function in a controlled environment. The CAHAI is a standardized test in which the participant is asked to complete a series of functional tasks utilizing both hands. This test adds bilateral functional tasks that are not primarily assessed in the WMFT. It also has been used and validated with persons after stroke (Barreca, Stratford, Masters, Lambert, & Griffiths, 2006). These outcome measures and the use of a single group repeated measures design aims to assess the preliminary effectiveness of this intervention. However, only considering the effectiveness would not have provided information on home exercise or the experiences of the participants that was thought to be crucial to the overall success of the intervention in the future. What if the participants felt the game was childish and played it less for that reason? Or felt that the game was too challenging to setup independently? Both of these concerns would not be formally addressed in a purely quantitative study using the outcome measures described above. For that reason, consideration of procedural methods was necessary.

As stated previously, procedural questions can be answered using either quantitative or qualitative methods. It was determined that following the participants experience from the beginning of the research process through to the end would be beneficial. Therefore, the type of procedural research can be considered longitudinal in design. For the purpose of this project, it was thought that qualitative methods would provide a robust way of exploring the experience that persons had with the intervention and give a degree of flexibility. The use of questionnaires was possible, however, there was a chance that responses would be limited to the content that was selected or already included in the questionnaire, allowing for bias. It was determined that one-on-one qualitative interviews at two time points in the research process would allow for a detailed exploration of the participants' experiences with past home exercise programs and the home program under investigation. In addition, the qualitative data had the potential to provide insight into general barriers and supports to home exercise that others could use in future research and clinical practice.

The use of mixed methods in the study described above provides the opportunity to assess the effectiveness of an intervention in the early phases of development, while identifying potential areas for improvement and unintended consequences. It should be noted that there are challenges to completing research in this way. One primary challenge is the time it takes to complete qualitative data collection and analysis. If the interviews were to occur at the same time as the other performance base outcome measures, talking about their experiences could affect the participants' performance on the tests or if the interviews were done second it could influence their opinions of the home program. Nevertheless, the opportunity to answer multiple procedural questions relating to the experience of the intervention and barriers and supports to use is considerably helpful in this early developmental phase of the research. The above example of a mixed methods design illustrates how mixed methods approaches; specifically those that occur concurrently can provide an opportunity to answer outcome and procedural questions.

Conclusions

Rehabilitation intervention after stroke is a critically important aspect of stroke recovery (Roger et al., 2011). Further rehabilitation research is needed to advance the strategies and interventions available to persons after stroke. Rehabilitation researchers can use quantitative and qualitative research methods to develop and test interventions for persons who have upper extremity impairments after stroke. The type of question that is being asked (i.e., outcome or procedural) will influence the selection of quantitative or qualitative methods. Outcomes research requires the use of quantitative methods in order to reduce outside influences and test the efficacy or effectiveness of an intervention. Procedural research can implement qualitative or quantitative methods to gain further information on the how or why of an intervention. While studies often address either an outcomes question or a procedural question, the use of mixed methods provides an opportunity to address both types of questions, especially when quantitative and qualitative methods are used concurrently.

CHAPTER 2

NEUROGAME THERAPY: A PRELIMINARY INVESTIGATION OF AN UPPER EXTREMITY HOME PROGRAM FOR PERSONS AFTER STROKE

There are a total of 7 million persons with stroke in the United States and approximately 795,000 persons having a new stroke each year (Roger et al., 2012). Over 1.1 million stroke survivors experience difficulties in everyday activities (Centers for Disease Control, 2009). Furthermore, 50% of persons after stroke experience difficulty using their impaired upper extremity at 6 months post stroke (Roger et al., 2012). The impairments in upper extremity motor function have been found to be associated with decreased quality of life in multiple domains including self-care, usual activities, pain/discomfort, and anxiety/depression (Franceschini et al., 2010).

Persons with poor upper extremity motor function after stroke can have a variety of impairments. Two common impairments are hemiparesis and spasticity. Hemiparesis consists of decreased motor control with secondary muscle weakness that occurs on one side of the body, typically the side opposite the location of the stroke. Spasticity results from over activity of the stretch reflex that is common after stroke (Kheder & Nair, 2012; Kong, Chua, & Lee, 2010; Watkins et al., 2002). This causes difficulty with selective muscle activation and overuse of co-contraction of agonists and antagonists, leading to an inability to achieve movement in typical activation patterns (Kheder & Nair, 2012). Estimates on the number of persons who experience some form of spasticity post stroke vary from 38% to 76% (Kong et al., 2010; Watkins et al., 2002). Hemiparesis and spasticity make it difficult for persons to regain use of their impaired upper extremity and resume engaging in daily activities (Watkins et al., 2002).

While impairments can be severe, persons after stroke can partially improve motor function with therapy and repetitive practice of specific tasks (Oujamaa, Relave, Froger, Mottet, & Pelissier, 2009; Urton, Kohia, Davis, & Neill, 2007). Physical and occupational therapists can use a variety of different treatment approaches with persons after stroke to address hemiparesis and spasticity. Recent studies demonstrate that permanent improvements in motor control can be achieved with adequate practice of specific activities, where the person is motivated and the demands on the nervous system are gradually increased (Kleim & Jones, 2008). Most current approaches to outpatient therapy provide too little practice to effect recovery in the chronic phase of stroke. Data from the Behavioral Risk Factor Surveillance Survey (Centers for Disease Control, 2007) reported that only 30.7% of stroke survivors receive outpatient therapy. Of those that receive outpatient therapy the amount is variable, with a person in the first year after a stroke receiving a median of six outpatient therapy visits (25^{th} to 75^{th} percentile ranged from 1-21) (Chan et al., 2009). In contrast, the amount of practice needed to induce functional improvements for persons in the chronic stages of stroke is extensive (Oujamaa et al., 2009; Pang, Harris, & Eng, 2006). For example, one study found that at least 57 hours of practice was needed to achieve functional gains in a person more than six months post stroke (Oujamaa et al., 2009). Current typical outpatient therapy provides insufficient practice time for motor recovery during treatment sessions. While outpatient therapy can be extended through home programs, adherence is generally poor (Touillet, Guesdon, Bosser, Beis, & Paysant, 2010). Barriers to adherence to exercise reported by persons after stroke in one study included musculoskeletal issues, fatigue, lack of time, family obligations, depression, and lack of enjoyment (Jurkiewicz, Marzolini, & Oh, 2011).

Given the challenges faced by persons after stroke and therapists in providing sufficient and specific practice, we sought to address these issues through a preliminary evaluation of a home-based program that combined surface electromyographic (sEMG) biofeedback with a computer game. sEMG biofeedback is a technique that has been used in motor rehabilitation following stroke since the 1960s (Woodford & Price, 2007). Typically, sEMG biofeedback provides information to the patient about their muscle activity through use of a light bar or auditory sound that indicates to the patient that he or she is activating the appropriate muscle (Woodford & Price, 2007). While the evidence base for sEMG biofeedback is inconclusive (Moreland & Thomson, 1994; Woodford & Price, 2007), several small studies have found it to be of benefit to persons after stroke for upper extremity motor recovery (Doğan-Aslan, Nakipoğlu-Yüzer, Doğan, Karabay, & Özgirgin, 2012; Moreland & Thomson, 1994; Woodford & Price, 2007). Combining this biofeedback method with an engaging home-based computer game was thought to potentially increase motivation to practice using the upper extremity by making it more enjoyable. Additionally, the use of sEMG biofeedback provides an opportunity to give specific feedback related to how the muscles are being activated as an agonist/antagonist pair over multiple repetitions. Specificity and repetition are two elements found to induce neural plasticity (Kleim & Jones, 2008). The primary aim of this study was to gather preliminary evidence on the effectiveness of sEMG biofeedback through an engaging computer game to improve upper extremity motor performance in adults after stroke who were chronically impaired. It was hypothesized that participants would improve voluntary muscle activation and functional performance on outcome measures.

Methods

Study Design

The study design was a single blinded one-group repeated measures design: A1, A2, B, A3 (A=Assessment, B=Intervention). A1 and A2 were scheduled approximately four weeks apart as able. A3 occurred within one week immediately after the intervention. See Figure 2. This design was selected because of the heterogeneous nature of persons after stroke and the preliminary nature of this investigation. Procedures received approval from the University of Washington's Human Subjects Division and all participants signed informed consent forms prior to beginning the study.

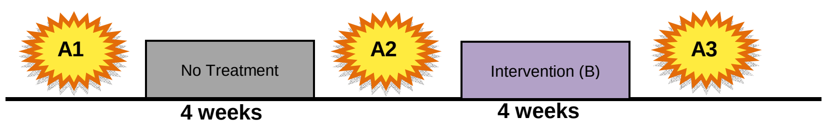

Figure 2. Schematic representing assessments, baseline, and intervention periods

Participants

Participants were a convenience sample of volunteers who were at least six months post-stroke and were between the ages of 40 and 70. To be included in the study participants needed to have mild to severe impairment of the upper extremity as self-rated on the Manual Ability Classification System (MACS). The MACS (McConnell, Johnston, & Kerr, 2011) was originally developed for children with cerebral palsy, however, the descriptions of the levels of function were determined to be general enough for use in screening this population. The rating scale goes from Level I through Level V, level I indicated typical function and a Level V indicated severely limited function of the limb. Also participants had to be cognitively able to give informed consent, determined by performance on the Pfeiffer Short Portable Mental Status Questionnaire

(Pfeiffer, 1975) or a series of orientation questions and direction following tasks for persons with aphasia, and have vision and hearing sufficient to interface with the computer. Participants were excluded if they: (1) had a skin condition that would interfere with the assessment or intervention, (2) reported significant pain in their affected upper extremity, (3) had a secondary neurological diagnosis such as Parkinson's disease, (4) had a contracture at the wrist that would prevent the wrist from being passively extended to a neutral position, (5) had used neurolytic injections in the previous four months and/or had variations in dosage of oral anti-spasticity medication in the previous 3 months.

Twelve participants were eligible and enrolled into the study after completing and signing informed consent. Of these initial twelve, 9 completed all three assessments, 2 withdrew secondary to lack of time to participate, and 1 was asked to withdraw secondary to a change in his medical condition during the study. The characteristics of the 9 participants who completed all three assessments are presented in Table 3.

Table 3

Participant Characteristics for Quantitative Outcomes

ID	Age	Gender	Hemiplegic Side	Years Post Stroke	In Therapy	MACS	Self-Reported Location
1	53	Male	Left	5	Yes	V	Unknown
2	47	Female	Right	3	Yes	IV	Brainstem
3	67	Female	Right	3	Yes	IV	Unknown
4	69	Male	Right	2	No	IV	Basal Ganglia
5	54	Female	Right	1	Yes	IV	Brainstem
6	54	Female	Left	9	No	IV	Parietal/Frontal
7	68	Male	Right	9	No	IV	Frontal
8	58	Male	Right	6	No	IV	Unknown
9	69	Male	Left	27	No	IV	Unknown

Intervention

The Neurogame Therapy system consists of a laptop, Neurogame Therapy box, wired cables, and disposable electrodes that attach to the skin. The Neurogame Therapy system box uses a modified Neurochip to convert bi-polar sEMG from two muscle groups, into computer signals that can operate a computer mouse in two directions, which controls the play in a computer game. The sensitivity of the system can be adjusted to detect very low levels of activation depending on the level of the person's impairment. For each participant, the minimum level of muscle activation required to play the game was adjusted to match the participant's level of impairment, thus allowing persons with minimal muscle activation capability to participate. These levels were adjusted as needed during the intervention phase to facilitate challenging and successful game play. The Neurogame interface allowed for recording sEMG during each game play session as well as the length and number of sessions.

Participants used the muscle activity in their affected wrist flexors and extensors to play the commercially available computer game, Peggle (Rothstein & Tams, 2007). In this game, participants attempted to clear the board of orange pegs by identifying the correct angle to send a ball to make contact with a peg (Figure 3). Participants selected the angle using their affected upper extremity and sent the ball to the peg on the screen by controlling the computer mouse using the less affected hand.

Figure 3. Screenshot of Peggle used in Neurogame Therapy (Rothstein & Tams, 2007)

The amount of muscle activity needed to play the game was altered as needed by the researcher in order to create the 'just right' challenge for the participants. The game could be setup up in two ways: one setup focused on selective muscle activation (i.e., trying to quiet one muscle group while the other was on) while the other trained activation of a weak muscle group independent of the activity of the opposing muscle group (i.e. one directional game play). Adjustments in gains from sEMG of the wirst flexors and/or extensors required to move the computer cursor to play the game were made throughout the intervention period as appropriate for individual participants.

Measures

Amount of game play. The number and length of each game play session was recorded by the computer interface and stored on the computer. The number of sessions completed by each individual was counted. A session was counted if there was a corresponding data file that lasted more than 5 minutes. It was decided that a data file less than five minutes was not long enough to indicate meaningful game play. The average number of minutes of game play/session was calculated for each participant by dividing the total number of minutes over the number of game play sessions.

Surface electromyography (sEMG). The sEMG was collected using the Bagnoli-16 channel system and six bar electrodes (Delsys, USA) that were adhered to the skin with an adhesive skin interface. Prior to placement the skin was prepared with a fine grain abrasive lotion in order to remove the dead skin cells. This was followed by rubbing the locations with alcohol to remove any debris and skin oils, in order to create the best environment for recording the electrical signals from the muscles. The electrodes were placed over the motor points for the upper trapezius, anterior deltoid, biceps, triceps, wrist flexors and wrist extensors of the participants' affected extremity (Cram, Kasman, & Holtz, 1998). Measurements for the electrode placements were recorded on a diagram for future testing sessions. Variables of interest for sEMG included: maximal sEMG values recorded during a maximal voluntary contraction from the wrist flexors (MVC Flexor) and wrist extensors (MVC Extensor), as well as, the co-contraction ratios for the wrist extensors/wrist flexors for the reaching (Co-contraction Reach) and extensor range of motion (Co-contraction Extension ROM) movements. See Appendix A for further details of the reduction and calculation of these variables. An increase in the co-contraction ratio implies an improvement in selective muscle activation.

Joint kinematics. Three-dimensional trajectories for the kinematic analysis were collected using reflective markers and a Qualisys* Oqus 300 camera system featuring eight cameras capturing marker data at 100 Hz. The OQUS system runs on a Dell Optimus PC running Windows XP and Qualisys Track Manager (QTM) software. Prior to data collection the camera system was calibrated to have residuals no greater than 3mm for each camera. Eight reflective markers were placed on the participant's affected upper extremity and trunk in the following locations: head of the third metacarpal, ulnar styloid, radial styloid, lateral epicondyle, bilateral acromions, sternal notch and forehead. One marker was also placed on the cup, which was used for the reaching task. The participants then completed a reaching task and active range of motion at the wrist (described in Procedures section) while both sEMG and kinematics were captured. The measurement of joint kinematics was completed in order to identify any potential change in upper extremity movement efficiency as measured by the variables of overall reach time and number of movement segments. See Appendix A for further details of the parameters and calculation of these variables.

Activity tests. Participants were videoed during two tests of functional use of the hand as secondary measures in order to capture changes in upper extremity function. The participants were tested using standardized procedures by one of three team members. Team members were trained through practice or observation to administer the tests using the protocols provided in the manuals. An occupational therapist with 20 years of experience, who was unaware of the dates of the participants' videos, rated the participants' performance on the two measures of upper extremity function.

The first activity measure was the Wolf Motor Function Test (WMFT). This is a unilateral activity test used to evaluate upper extremity function during gross and fine motor activities. There are 15 activities for function and two for strength. All 15 items are timed and the participants are asked to do them as rapidly as possible. Participants receive a functional activity score on a scale of 0 to 5. "0" indicates that a participant did not attempt a task where a "5" indicates completion of the task with normal movement. The total functional activity score for this test is the average of the 15 test items. This measure has been used frequently with persons after stroke who have upper extremity impairment. Nijland and colleagues (2010) found that the

WMFT measures one one-dimensional construct (Cronbach's alpha = 0.982) and its subscales (Functional Activity Score, Time, and Strength) are associated with the Action Research Arm Test (r = 0.86, -0.89, 0.70). The WMFT was also found to have a high test-retest reliability (Pearson r = 0.90) (Morris, Uswatte, Crago, Cook III, & Taub, 2001). Previous research had found that the minimal detectable change for the Functional Ability Score is 0.1 to 0.37 and for Time was 0.7 to 4.36 from two separate research studies (Fritz, Blanton, Uswatte, Taub, & Wolf, 2009; Lin et al., 2009).

The second upper extremity activity measure was the Chedoke Arm and Hand Inventory-9 (CAHAI-9). This measure is a bilateral activity test used to evaluate use of both upper extremities together. Unlike the WMFT, this test is not timed. Participants are scored on an ordinal scale from 1-7 that is similar to the Functional Independence Measure (Keith, Granger, Hamilton, & Sherwin, 1987) where 1 is Dependent (Affected arm performs less than 25 percent of the task) and 7 is Independent (Affected arm complete 100 percent of the task). Scoring is based on the assessment of the quality of use relative to the components of stabilization and manipulation, as well as the amount of assistance needed during the task. The sum of the individual item points over the number of total possible points is calculated as the percent score. This test was developed for use with persons after stroke based on a review of the literature and a survey of persons after stroke (Barreca et al., 2004). The original 13 item test was found to have high interrater reliability ($ICC_{2,1}$ = 0.98) and it has been found to be sensitive to change with a clinically meaningful difference being more than 6 points (Barreca, Stratford, Lambert, Masters, & Streiner, 2005). The CAHAI-9 has been found to be comparable in psychometrics to the original 13 item test (Barreca, Stratford, Masters, Lambert, Griffiths, et al., 2006).

Procedures

In the first assessment participants completed a health history form. All subsequent assessments began with the participant stating whether or not their therapy routine has changed since the previous assessment. Then participants were videoed while they performed the WMFT and CAHAI test items. After completion of these activity measures, sEMG electrodes were applied. Participants then completed three different activities while connected to the sEMG.

First we identified their maximal voluntary contraction by having participants deliver force against a stabilized dynamometer using wrist extension followed by wrist flexion. After this task participants had the kinematic markers placed on the landmarks described above. Subsequently, kinematic and sEMG data collection occurred simultaneously over the next two tasks. The second task was modeled after work done by Murphy, Willén, and Sunnerhagen (2011), and included asking the participants to reach out to pick up a cup of water that was placed at arms length away in line with the person's midline. If a participant was unable to pick up the cup they were instructed to reach out as if they were going to pick up the cup but instead simply make the cup move. The third task was active range of motion at the wrist. Participants' affected upper extremity was supported at the forearm during this task. They were instructed to move their wrist as far as they could, not as hard as they could. Each of these tasks had a minimum of five trials; extra trials were completed if there was an error on the researchers behalf related to data capture or if the recorded signal was compromised due to a loose electrode or prolonged muscle spasm.

Following the second pre-intervention assessment, the participants began training in the Neurogame Therapy program. The training consisted of calibrating the game to the participant's upper extremity sEMG, practicing playing the game, and practicing setting up the sEMG electrodes for home use. Participants received up to five training sessions.

Home setup was completed for 8 out of 9 participants. One participant determined after the beginning of training that her home was not able to accommodate the game. Therefore, she completed game play at the University of Washington. The participant was able come to the University 1-3 times a week depending on her schedule and played the game unsupervised in a quiet room in order to simulate a home setting. She was given assistance to address technical difficulties as needed, similar to what would have occurred if she had been playing at home.

With the remaining participants, a suitable space for the game system was located in the participant's home and the area was evaluated for electrical interference. If available, the system was connected to the participant's wireless Internet to allow the researchers to access the system remotely in order to adjust the game settings. The participants then practiced the Neurogame therapy in their home for four weeks with additional weeks added if technical difficulties were encountered to allow for a total of 4 weeks of game play. Technical difficulties that caused such a delay occurred with 3 out of the 9 participants. It was recommended that the participants use the game five days a week for no more than 45 minutes each day.

Data Analysis

After completion of data reduction and scoring (See Appendix B), the data were entered into SPSS Version 18 for further descriptive and statistical analysis. Variables that contained multiple trials (sEMG and kinematics) were averaged so that each participant had a calculated mean for each variable of interest. Secondary to the small sample size and preliminary nature of the data non-parametric group statistics, specifically the Wilcoxon Signed Ranks Test was used to compare performance across no-treatment (A1 to A2) and treatment (A2 to A3) study phases.

The alpha level was set at 0.05. Descriptive statistics and graphs depicting each outcome variable were then completed to visually assess the performance of all individual participants.

Results

Amount of Game Play

Participants amount of game play is presented in Table 4. Only three participants completed or exceeded the number of sessions recommended. Another two were very close in completing the recommended number of sessions. The remaining participants played the game about two to three times a week. The average length of session ranged from 24 minutes to 62 minutes.

Table 4

Amount of Home Game Play

Participant	Style*	Number of Sessions	Average Length of Sessions (minutes)
1	2	10	24
2	1	19	62
3	1	8	42
4	1	38	42
5	1	15	31
6	1 &2	12	38
7	1	19	39
8	1	24	39
9	1	38	38

* Style of Game Play: (1) selective activation; (2) increased activation of one muscle group

Analysis of Outcomes at the Group Level

sEMG. Only eight participants had complete data for extensor MVC and due to technical difficulties only seven participants had complete data for flexor MVC. See Appendix A for details. When comparing the mean MVC extensor and flexor levels for the group, no statistically significant differences were found across either the no-treatment or treatment time periods. This was also the case when comparing normalized co-contraction ratios for extensor active range of motion. A statistically significant difference was found across treatment (A2 to A3) for the normalized co-contraction ratios during the reaching task (Z= -2.380, p = 0.017).

Table 5

Group sEMG Analysis Across All Assessments

Variable	A1 Mean (SD)	A2 Mean (SD)	A3 Mean (SD)
MVC Extensor (microvolt at muscle)	30 (29)	41 (33)	37 (26)
MVC Flexor (microvolt at muscle)	38 (19)	42 (25)	37 (14)
CC-Extensor AROM	2.87 (1.55)	3.39 (4.90)	3.54 (3.25)
CC-Reach	2.47 (2.34)	2.98 (5.02)	5.00 (8.41)
		* (A2 to A3)	

* $p < 0.05$

Note: An increase in the above measures demonstrated increased independent activation of the desired muscle group.

Kinematics. Eight participants had data that could be used for group analysis from the kinematic portion. One participant’s data was not usable due to a researcher error in setup during A3. Of the two variables generated from the reach task (reach time, number of movement segments), while the data trended toward improvement, neither demonstrated a statistically significant difference across either the no-treatment or treatment time period. See Table 6 for details.

Table 6

Group Kinematic Outcomes Across All Assessments

Variable	A1 Mean (SD)	A2 Mean (SD)	A3 Mean (SD)
Reach Time (seconds)	4.35 (3.76)	3.06 (2.07)	2.79 (1.09)
Movement Segments	7 (6)	5 (5)	4 (3)

Activity Measures. No statistically significant differences were found across time on the WMFT in the Functional Activity Score, Time, or Grip Strength. Furthermore, in the bilateral functional outcome measure, the CAHAI, no significant differences in score, across all time points were found. See Table 7 for details.

Table 7

Group Activity Outcomes Across All Assessments

Variable	A1 Mean (SD)	A2 Mean (SD)	A3 Mean (SD)
WMFT Functional Activity Score+	1.79 (0.71)	1.77 (0.68)	1.79 (0.66)
WMFT Time (s)	67.54 (35.09)	66.07 (33.69)	67.85 (35.17)
WMFT Grip Strength (kg)+	5 (6)	6 (6)	7 (8)
CAHAI Percent Score+	.27 (.18)	.26 (.17)	.25 (.17)

Note: + Higher number indicates improved performance

Analysis of Outcomes at the Individual Level

In order to further analyze the data and potentially identify who may have responded best to the intervention visual analysis based on graphing the individual means of each outcome variable over time was completed. To do this the graphs depicting each individual's performance over time were inspected to determine if a change occurred over A2 to A3 taking into account the performance change over A1 to A2. See Appendix B for graphs depicting the individual's performance on each outcome measure.

sEMG. When visually analyzing MVC levels of the extensors and flexors for each individual, there was considerable variability. See Table 8. Only three participants demonstrated improvement in extensor MVC level over A2 to A3 period or maintenance of performance between A2 and A3 where a decline in performance was observed over A1 to A2. Flexor MVC showed less variability with only 2 participants demonstrating an improvement.

Table 8

Visual Analysis Results by Participant Across All Outcome Measures

ID	CC-Reach	CC-Ext AROM	Ext MVC	Flex MVC	Reach Time	Reach Segments	Time WMFT	Grip WMFT	FAS WMFT	CAHAI
9	Trend in expected direction	Trend in expected direction	Trend in expected direction	Missing Data	Trend in expected direction	No Change	Trend in expected direction	Trend in expected direction	Trend in opposite direction than expected	Trend in opposite direction than expected
4	Trend in expected direction	Trend in expected direction	Trend in opposite direction than expected	Trend in expected direction	Trend in expected direction	Trend in expected direction	Trend in expected direction	Trend in opposite direction than expected	Trend in expected direction	Trend in opposite direction than expected
3	Trend in expected direction	Trend in expected direction	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in expected direction	Trend in opposite direction than expected	No Change
1	Trend in expected direction	Trend in expected direction	Missing Data	Missing Data	Trend in opposite direction than expected	No Change	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	No Change
6	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in expected direction	Trend in expected direction	Missing Data	Missing Data	No Change	Trend in opposite direction than expected	No Change	No Change
7	No Change	Trend in opposite direction than expected	No Change	Trend in opposite direction than expected	Trend in expected direction	Trend in expected direction	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in expected direction	No Change
8	Missing Data	Missing Data	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	No Change	Trend in expected direction	Trend in expected direction	Trend in opposite direction than expected
5	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in expected direction	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	No Change	Trend in expected direction
2	Trend in expected direction	Trend in expected direction	No Change	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	Trend in opposite direction than expected	No Change	Trend in opposite direction than expected	Trend in opposite direction than expected

Abbreviations: CC-Reach – Co-contraction Ratio for Reach Task

CC-Ext ARM – Co-contraction Ratio for Extension Active Range of Motion

Ext MVC – Extensor Maximal Voluntary Contraction

Flex MVC – Flexor Maximal Voluntary Contraction

Reach Time – Total time of reach task

Reach Segments – Total number of movement segments calculated during the reach

Time WMFT – Average number of seconds needed to complete the tasks on the Wolf Motor Function Test

Grip WMFT – Average grip strength in the across three trials on the Wolf Motor Function Test

FAS WMFT – Functional Activity Scale on the Wolf Motor Function Test

CAHAI – Percent score on Chedoke Arm and Hand Activity Inventory

Missing Data

Trend in expected direction

No Change

Trend in opposite direction than expected

While changes in MVC levels for both the flexors and extensors were variable, changes in the co-contraction ratios across the reach and extensor AROM tasks were fairly consistent across individual participants. Five out of eight participants showed a decrease in co-contraction ratios with higher ratios indicating more extensor activation, while the rest showed no change or an increase in co-contraction.

Kinematics. When visually analyzing the temporal-spatial variables three out of the eight participants demonstrated a decrease in reach time, and two demonstrated a decrease (improvement) in number of movement segments during the reach phase.

Functional Outcomes. Participants' performance on Functional Activity Scale as part of the WMFT was also variable. However, two participants showed a slight improvement after a decline in baseline and another participant showed maintenance of performance with no continued decline over the intervention period. Similar variability was also observed in time to complete tasks and grip strength with three participants showing improvements in grip strength and two showing improvement in WMFT time. The remaining participants either demonstrating no change or a decline. Changes seen in time both improvements and declines were at or above the minimal detectable change reported by Fritz and colleagues (2012). The CAHAI individual analysis indicates that most participants had no change on this measure and several had performance decrease slightly over time.

Discussion

A total of nine adults at least 6 months post-stroke completed the baseline and intervention phases of this study that aimed to evaluate the preliminary effectiveness of the use of Neurogame Therapy as a home program. Half of the participants used the game at home either above or close to the frequency recommended. Duration of game play on average was slightly under the 45-minute recommendation. This suggests that five sessions per week may not be a feasible amount for all participants. Results from a companion qualitative study found that participants on the whole found the game enjoyable, but they did have recommendations to improve the ease of use and age appropriate nature of the game.

Group analysis

The results of the group analysis found a statistically significant decrease in the amount of co-contraction present during the simulated reaching task. This change suggests that the intervention, which was designed to effect co-contraction, was functioning as anticipated for the group as a whole. A lack of additional findings on other outcomes may suggest that this intervention may benefit from the addition of other types of upper extremity intervention in order to impact functional outcomes. This is consistent with some other findings in traditional sEMG biofeedback research that found that sEMG combined with other conventional therapies had the most success (Doğan-Aslan et al., 2012). It is also possible that the small sample size limited the ability to detect an effect on functional activity variables.

Although no statistically significant difference was found for co-contraction during extensor AROM, a small decrease was observed after intervention and present on visual inspection of the individual results. The difference observed in the two co-contraction outcomes could be related to the nature of the outcome tasks. In the extensor AROM task participants' forearms were rested on the researcher forearm in order to decrease extraneous arm movements, while in the reaching task participants were able to use their entire arm and trunk. This difference made the reaching task more similar to how participants interfaced with the game using movements of their whole arm and trunk in addition to the necessary activation pattern at the wrist. One hypothesis for this finding is that this intervention effect on co-contraction may generalize to other reaching type tasks but does not necessarily transfer to tasks that require different movement patterns. This is consistent with one of Kleim and Jones' (2008) principles of experience dependent plasticity, specificity, which states that exactly how a person receives training will impact how plasticity presents outside of training.

Individual Analysis

Individual visual analysis of results allows for discussion of individuals that responded positively to the intervention across several variables and those who did not respond as well. Participant 3 and 9 made improvements across multiple measures. Participant 3 showed the following changes: (1) an increase in flexor MVC over the intervention period, (2) improvement in co-contraction in both the reach and extensor ROM tasks, (3) improved reach efficiency, and (4) improvement in the WMFT functional activity score and time to complete tasks. This participant had intact sensation and some use of her upper extremity. One possible explanation for this participant's favorable response is that she completed her game play at the University of Washington because she was unable to take the game system home. Although every effort was made to make the setting most like home (i.e. participant completed setup independently, played the game without supervision), the participant did have more exposure to the investigator to ask questions and received immediate troubleshooting if there were technical difficulties. It is of note that this participant had fewer game play sessions per week because she was only able to come to the University 1-3 days per week. Despite fewer days of game play, this participant made improvements on several outcomes. This participant was also receiving 1 to 2 days of therapy a month throughout the entire study, which may have contributed to Neurogame Therapy success.

Participant 9 also demonstrated positive changes across multiple measures. This participant showed improvement across all sEMG outcomes, for which he had data. In addition his reach time improved showing a possible increase in reaching efficiency. This participant had some wrist and digit extension in his affected arm prior to beginning the study, which could partially explain his result. It is interesting to note that he was the furthest post-stroke, 28 years. This suggests that changes can be made to muscle activation patterns, reaching efficiency and strength even years post stroke. However, this participant did not demonstrate positive changes in the functional activity scores, which may imply again that in order to transfer these sEMG changes into function, additional conventional therapy such as constraint induced movement therapy (Sirtori et al., 2009), neurodevelopmental therapy, or a biomechanical (Radomski & Trombly, 2007) approach may be needed.

Participants 2 and 5 were on the other end of the spectrum and visual analysis did not demonstrate much improvement across outcome measures. Both participants demonstrated some positive change on the sEMG outcome measures but for Participant 2 no other positive changes were noted. Participant 5 only demonstrated minimal improvements on the time subscale of the WMFT and the total score of the CAHAI. Both of these participants were female, and both reported that the location of their infarct was in the brainstem. Brainstem injuries involve more motor descending pathways than a cortical infarct; which could explain the poor response seen in these two participants (Shumway-Cook & Woollacott, 2011). In addition to location of infarct, both participants are female and of the four female participants only one demonstrated positive findings across several outcome measures. This is consistent with findings that women have more disability after stroke and poorer functional outcomes compared to men (Roger et al., 2012).

Given the findings of this study more research is need to determine the effectiveness of Neurogame Therapy. Results from this study will be used to power a larger more robust effectiveness trial with modified inclusion and exclusion criteria based on the results of this study.

Limitations

This study had several limitations, some of which were related to the sample. For this study a sample of convenience was used and despite having 12 persons initially enrolled only 9 completed the study. In addition, the sample had persons at many levels of function. Given the size and variability of the sample it is not surprising that we found only one statistically significant difference. However, given the preliminary nature of this investigation having a range of history, and movement variability in the participants was advantageous. This allowed for speculation regarding who may benefit most from this program taking into account certain characteristics (i.e., gender, age, level of function). Another limitation was the lack of control for confounding factors, such as receiving other motor therapies. This makes it more difficult to attribute findings entirely to the study. It should be noted that most participants who were receiving therapy were receiving a small amount (i.e., 1 to 2 times a month). Finally, it is possible that the dosage was not appropriate and that participants may have needed more time or more adjustments to the settings to get the 'just-right' challenge in order to maximize outcomes.

Conclusion

Neurogame Therapy is an innovative combination of biofeedback and computer games, which are motivating, that targets decreasing co-contraction within a muscle agonist/antagonist pair or increasing selective activation of a particular muscle group. In this preliminary study with 9 participants the focus of intervention was improvement of wrist flexor and extensor muscle activation. We found an effect at the level of sEMG, which indicates that the game is making the intended changes in co-contraction, but no changes at the functional activity level. Further visual analysis suggests that this home program might be most suitable for persons with some degree of digit movement and those who have had a cortical infarct. In addition Neurogame Therapy may benefit from the inclusion of more conventional therapies to assist in the transfer of changes at the muscle activation level to changes in function. Further research is recommended to investigate the efficacy of Neurogame Therapy as a home program in adults after stroke.

CHAPTER 3

PERSPECTIVES OF STROKE SURVIVORS ON HOME EXERCISE AND NEUROGAME THERAPY

Over 7 million Americans over the age of 20 have had a stroke (Roger et al., 2012). The after effects of stroke are varied and can include impairment in motor function, sensation, cognitive abilities and communication. Fifty percent of stroke survivors report hemipaersis at six months post-stroke (Roger et al., 2012). Poor motor function of the upper extremity is often reported, a factor that can predict decreased quality of life in several domains of the Euro QoL-5D such as self-care, usual activities, pain/discomfort, and anxiety/depression (Franceschini et al., 2010). The effect that upper extremity function has on a person's ability to participate in meaningful activities heightens the rehabilitation professional's focus and attention on this area during treatment.

Over the last two decades there has been a concerted effort to understand how the brain functions after injury, such as a stroke, and what methods can be used to improve motor function and other capacities. Experience dependent neural plasticity, or the ability of the human brain to change based on experience, has led to new thinking about recovery (Kleim & Jones, 2008). Based on recent research, Kleim and Jones (2008) outlined principles that are key to creating experience dependent neural plasticity. One of the key principles is repetition, which states that in order to create neural changes a task needs to be repeated multiple times. Furthermore, this practice needs to be at the correct intensity and done at the most opportune time for recovery. Finally, practice must be specifically focused on a particular type of movement as well as being salient or of value to the person involved. This set of principles, thus, highlights the importance of repetition, intensity, timing, specificity and salience for interventions that are directed at improving recovery of motor function.

From research in experience dependent neural plasticity, we have seen development of intervention approaches like constraint induced movement therapy (Lin, Wu, Wei, Lee, & Liu, 2007; Sirtori et al., 2009; Wolf et al., 2010), robotic assisted therapy (Lo et al., 2010), electrical stimulation paired with surface electromyography biofeedback (Gabr, Levine, & Page, 2005; Meilink et al., 2008), and bilateral training (Coupar et al., 2010). One key element of many of these treatments is the intensive repetition of movements with the impaired upper extremity. Despite these and other techniques to improve upper extremity function the number of persons who continue to have hemiparesis in the chronic phase post stroke remains high (Roger et al., 2012).

One potential reason for this is the limited amount of post-stroke care that is typically received by persons after stroke. In 2005, the Centers for Disease control reported that only 30% of persons after stroke receive outpatient services and that this percentage was far lower than what would be expected if clinical practice guidelines were being followed (Roger et al., 2011). Furthermore, a study completed in a California system found that the average number of outpatient therapy visits typically provided to a person after stroke was only six (interquartile range of 1-21) in a years time, across all rehabilitation services (Chan et al., 2009). This suggests that persons after stroke receive a limited amount of opportunities for practice through direct rehabilitation services. Furthermore, while the number of repetitions needed to create lasting improvements is not known, research completed with persons after stroke demonstrated that neural plastic changes occurred with 100 repetitions of a specific movement per day over twelve days (Carey et al., 2002). However, research indicates that typical therapy sessions on average provide only 39 – 52 repetitions of active arm exercise per session and 12 – 32 repetitions of functional movements (Lang et al., 2009; Lang, MacDonald, & Gnip, 2007). This research on current upper extremity therapy, demonstrates an apparent gap between what is needed to improve motor function and what is usually or readily available to persons after stroke.

One strategy used in clinical practice to bridge this gap is use of a home exercise or activity program. There is a limited amount of information on how to address upper extremity function home exercise or activity programming for persons after stroke in physical and occupational therapy training texts (Bennett & Karnes, 1998; Gillen & Burkhardt, 1998; Logigian, 1982; Radomski & Trombly, 2007; Shumway-Cook & Woollacott, 2011; Sladyk, Jacobs, & MacRae, 2009; Umphred, 2007). Upon searching the research literature one will find that home exercise or activity programs are often used as the control treatment or as a part of a larger intervention (Askim et al., 2010; Badke, Sherman, Boyne, Page, & Dunning, 2011; Gabr et al., 2005; Macko, 2008; Page, Levine, Teepen, & Hartman, 2008) . Within the body of literature, home exercise or activity programs range from a one size fits all to an individualized approach (Askim et al., 2010; Page et al., 2008). Regardless of the degree of individualization, a typical home exercise program contains exercises patients are instructed to perform for a certain number of repetitions or sets. There is often a dosage given, indicated by how many times a day or week the exercises should be completed. Patients usually receive training in the exercises by the therapist through demonstration and practice. Handouts with pictures are often issued to ensure understanding of the exercises and may also serve as a reminder of what exercises have been assigned. Some therapists may request that patients keep a log to indicate how often they are doing these exercises in order to know when to modify the exercise program (Hutchinson & Winnegge, 2004; Page et al., 2008).

While home exercise programs are commonly used, research focusing on adherence to home exercise programs without concurrent therapy is low. For example, a study completed by Jurkiewicz, Marzolini and Oh (2011), found that after completion of an eight month exercise group, of graduated participants only 76% reported adherence to aerobic exercise (i.e., walking, water exercise, semi-recumbant cycling) and 50% reported adherence to resistance exercise (i.e., weight training with dumbbells, resistance bands or participants own body weight). Touillet, Guesdon, Bosser, Beis, and Paysant (2010) found that 3 months after the conclusion of an activity program for persons after stroke only 11% of the original participants were continuing with the prescribed amount of activity. While there is currently a limited amount of information on adherence to upper extremity programs, the above findings demonstrate that persons after stroke may face challenges with adhering to an independent home exercise program.

Despite difficulties with adherence to exercise programs by persons after stroke, exercise is recognized as important to the recovery of upper extremity function. Barker and Brauer (2005) completed three focus groups and two in depth interviews with persons after stroke to investigate how persons after stroke view recovery and the strategies or factors they think influence upper extremity recovery. They found that persons after stroke wanted to continue to work toward improvement and one of the ways they cited trying to do this was beginning and continuing exercise (Barker & Brauer, 2005). While this was recognized as key part to recovery, continuing with exercise was challenging due to lack of knowledge on how to proceed with exercises or how to start, as well as maintaining motivation. Others have studied barriers to general exercise in persons after stroke and have found that the following personal barriers were commonly reported: a lack of knowledge regarding exercise, a lack of energy, lack of motivation, and a feeling that exercise would not help (Rimmer, Wang, & Smith, 2008). In a study that examined home exercise for persons after stroke more specifically, similar barriers were identified, but the following issues were also noted, musculoskeletal issues, fatigue, lack of time, family obligations, depression, and lack of enjoyment (Jurkiewicz et al., 2011).

Given current research, persons after stroke see a value in exercise but face challenges when trying to adhere to prescribed exercise programs. The inclusion of technology as a part of rehabilitation programs is appearing more frequently in the research literature. Technology is being incorporated in part because it can allow for remote access to persons that can not get to healthcare facilities (Lum, Uswatte, Taub, Hardin, & Mark, 2006; Page & Levine, 2007) and it may be able to increase enjoyment of upper extremity rehabilitation (Burdea et al., 2011; da Silva Cameirão, Bermúdez I Badia, Duarte, & Verschure, 2011; Mouawad, Doust, Max, & McNulty, 2011).

Video gaming and virtual reality have been introduced into therapy in an effort to increase enjoyment of repetitive exercise. For home programs this may assist with adherence. Several studies have been conducted using off the shelf game systems, such as the Wii, in order to investigate the feasibility and potential effectiveness of these systems in improving upper extremity motor function with some promising results (Hijmans, Hale, Satherley, McMillan, & King, 2011; Mouawad et al., 2011; Saposnik et al., 2010; Yong Joo et al., 2010). In addition to these efforts, investigations of other virtual reality systems that use video games or a game interface are also underway with preliminary studies demonstrating positive results on a variety of measures (Combs et al., 2012; da Silva Cameirão et al., 2011; Schuck, Whetstone, Hill, Levine, & Page, 2011; Szturm, Peters, Otto, Kapadia, & Desai, 2008). For example, Combs and colleagues (2012) found changes in upper extremity kinematics but not in functional outcome measures after persons with chronic stroke used a repetitive gaming intervention.

While several of these studies have looked at the feasibility of using technology in therapy, few have explored participants' experiences or views beyond the use of questionnaires. However, some insight was gained on user perspectives in a study done by Lewis, Woods, Rosie, & McPherson (2011) where a semi-structured interview regarding the experience of participants' use of a virtual reality game for upper extremity rehabilitation was completed. Overall most participants enjoyed their experience and found that it challenged them. When comparing it to physiotherapy most participants reported that it would be a good adjunct, but would not replace traditional methods of therapy. These interviews also provided the authors with insight into future improvements for the virtual reality system such as decreasing environmental distractions in the game and allowing for competitions between users (Lewis et al., 2011).

Neurogame Therapy (NGT) is a game-based system that utilizes surface electromyography biofeedback to control a commercially available computer game for use as a home exercise program. Given that little is known about the experience of home exercise programs for persons after stroke and that home modalities are in need, it was considered important to explore user experiences when developing a home system. This would provide important information that could assist in determining the acceptability of this intervention in comparison to traditional home exercise programs. Therefore the focus of this study was to characterize the way participants used their upper extremity in daily activities, explore their experiences with previous home exercise programs, and describe their experience with NGT

Methods

Design

A preliminary study of NGT was designed to collect both quantitative and qualitative data on the effectiveness and acceptability of the intervention in adults post-stroke when used as a home program to address impairments in upper extremity function. The quantitative portion of the study used a repeated measures design A1,A2,B,A3. Participants completed quantitative outcome testing twice during the baseline period (A1 to A2). Then participants, after the completion of training used the game at home for approximately 4 weeks (B). Technical support was available as needed and game settings were changed periodically if the participant required a greater challenge. After the intervention period, participants came in for testing within a week after they finished using the game (A3). Results from the quantitative study are reported in a separate paper. For the qualitative portion of the study, reported in this paper, semi-structured interviews were completed at the first and third assessment points and are described in further detail below.

Sample

A sample of convenience was used. Each participant provided written informed consent and all study procedures were approved by the Human Subjects Division at the University of Washington. Participants were recruited via flyers that were handed out by rehabilitation professionals; at support group meetings; and posted on-line and in approved listserves. All participants were at least 6 months post-stroke with motor impairments on one side. Motor impairments ranged on the Manual Ability Classification System from having difficulty with managing objects to no active movement (McConnell et al., 2011). Participants also needed to have vision and hearing sufficient to complete the outcome measures and engage in the video game. Participants were excluded if they were non-English speaking, had substantial cognitive or communication deficits, or if they had recently altered their anti-spasticity management program or received neurolytic injections. For descriptive information on the participants please see Table 9.

Table 9

Participant Characteristics for Qualitative Portion

Pseudonym	Age	Gender	Hemiplegic Side	Years Post Stroke
Michael	53	Male	Left	5
Mary	47	Female	Right	3
Harriet	67	Female	Right	3
Gerald	69	Male	Right	2
Jennifer	54	Female	Right	1
Hannah	54	Female	Left	9
Brad	68	Male	Right	9
Wayne	58	Male	Right	6
George	69	Male	Left	27
Zac	43	Male	Left	1

Neurogame Therapy (NGT)

The intervention, NGT, is an augmented form of surface electromyography biofeedback. During NGT, the participant is able to control the cursor of a commercially available computer game using the muscle activity in the affected limb. In this study, we specifically directed the intervention towards improved motor control of the wrist flexors and extensors. The commercially available game Peggle (Rothstein & Tams, 2007) was used in NGT. In Peggle, participants aim a ball to eliminate orange colored pegs. In order to pass a game level one must clear all of the orange pegs from the screen. Levels of difficulty, in NGT, may be advanced in two ways: (1) levels advance from easier to more difficult requiring more strategy and control to aim and clear the orange pegs is needed; or (2) adjustments can be made to the amount of muscle activation needed to control the launcher for one or both muscles.

Qualitative Procedures

Participants completed two interviews, one at the first testing session and the second immediately following completion of the NGT intervention. In order to ensure participants could be comfortable expressing any positive or negative views about the game or the past experiences all interviews were completed by two interviewers that were not involved with the assessment or gaming portion of the study. A novice interviewer received training and feedback from the more experienced interviewer, including a practice interview. There was one instance where neither trained interviewer was available for a follow-up interview. In this case, another researcher completed the interview. In order to prepare, this interviewer reviewed several prior audio-recorded interviews for style and technique.

The interviews were semi-structured and used an interview guide (See Appendix C). The questions in the first interview focused primarily on obtaining information about how each of the participants used his or her arm at home, their previous experience with home exercise, and their use of technology. The second interview asked participants about their experience with NGT and if they noticed any changes in how they used their arm. All interviews were audio recorded. Persons with expressive aphasia at times used gestures or written words to communicate during the interview. In order to capture these alternative communication strategies, the interviewer described them for the audiotape.

Data Analysis

Audio recordings were transcribed and entered in Microsoft Word. In order to ensure the accuracy of the transcription, they were reviewed prior to coding by the primary researcher. Qualitative description as described by Sandelowski (2010) was used as a guiding framework for analysis. Qualitative description is a data near approach that attempts to minimize interpretation and attempts to describe what was found in the everyday terms used by the participants. With this in mind, the interviews were initially coded with a coding structure based on the interview guide. Additional codes were created in order to capture key topics that came up when participants were responding to questions throughout the interviews (See Appendix D). Coding was initially completed by the primary researcher and verified by a second researcher with extensive experience in qualitative analysis. The primary researcher and an experience qualitative researcher discussed any disagreements regarding a particular use of a code until a consensus was reached. From these codes themes were generated to describe the participants' use of their affected upper extremity, perceptions of past home exercise or activity programs, and their experiences and perceptions regarding NGT.

Results

A total of ten participants completed the nested one-on-one interviews, one of these participants due to outside medical issues was asked to withdraw from the quantitative portion of the study. The findings from these interviews are described below with separate focus on the pre-interview and post interview questions. All names used in this paper are pseudonyms.

Pre-Intervention Interview

Outcome: Upper extremity use. In order to understand the relationship that our participants had with their affected limb on a day-to-day basis we asked them to describe to us how they used their arm in daily activities. Several themes emerged.

Upper extremity use is challenging. All but one participant was able to name at least one activity for which they tried to use the affected limb in a functional way. For some participants this was using it to turn on and off light switches, for others it was incorporated into dressing and cooking activities. Appendix E contains a table, which provides a list of activities each participant reported performing. However, most participants felt that the use of their affected upper extremity was infrequent. For example, Mary stated, *"I really can't do a whole lot with it though. I can't you know get a cup or anything like that…You know, I pr- I… I don't use it. I – I* *don't use it really."* Additionally, Harriet said: *"I have tried to use it with opening doors or hanging- using it to hang up clothes. Um, to han- um… deal with putting clothes in the basket or washing and picking up the basket to (sigh) bring the clothes, um, upstairs. Um… the thing of it is, is that it's very [frustrating]. …Most of the things I do, uh, with my left hand."*

Even if participants had more functional use of their affected upper extremity prior to the intervention they tended to report that they did not use their affected upper extremity much and relied on their less affected limb for most tasks. Zac describes this: *"Well, at this point I really don't use it very much… I mean, there's a few things that I use it for like, um, I try and use it for door handles fairly regularly, or elevator buttons… but I don't really use it for eating at this point…I usually just end up trying to do it with my right arm, my right hand*." George states quite frankly: "*Unless I really have to u- involve both hands I, I do everything with the right (less affected upper extremity). Yeah*."

Upper extremity use is expected. When asked about using their upper extremity in daily activities many participants reported that they felt that they should be using their affected upper extremity more than they were. For instance, Zac felt that*: "[I] Probably need to be trying to make it do more than it is…What I mean I should be trying to make myself eat with it I guess. It seems like that's something I should- probably about time to be… forcing the issue on that or some- something."*

Michael reiterated this sentiment stating*, "I'm um chagrin to say that I don't use, I don't try to use it as much as I should."*

Some participants while recognizing that they could use their upper extremity more expressed that they were just learning how to use it or were unsure of how to use it. Gerald when asked about using him arm stated *"Not, not, uh, no. Uh, as much as I can, not very often. So, I* *think that, uh, I can use it more often…But, um… I'm just learning to n- use it so, I don't know*." Mary reports *"…And you know the one lady said, she said, 'You need to use it,' And, I'm like, but how do I use it?"*

These two themes illustrate that these participants with chronic stroke are attempting to use their affected upper extremity although it is infrequent. Furthermore most have received the message that it is important to use the affected limb, despite some uncertainties about how to do this.

Outcome: Home Exercise/Activity Programs. In attempt to understand the participants' perspectives on home exercise or activity a series of questions about their previous home programs was asked. From the participants' responses, three key themes emerged regarding home programs.

Home exercise programs are non-specific. When participants were asked about their home exercise programs responses varied greatly. It appeared that most programs consisted of active and passive range of motion exercises, strengthening exercises, and some functional activities (See Appendix E for more detailed descriptions of participants home programs). Michael described his program as, *"I have a few exercises I do at home… OT exercises. Like if I can get my hand open - I have a lot of spasticity - then I try to get it around the refrigerator door and open and close that to a metronome for like 5 minutes."* Four participants mentioned that they had used electrical stimulation at home; two of them reported having to send the device back at a certain point.

While most participants could recall some exercises or activities that they were instructed to do at home, only a few participants recalled how often they should complete them or the number of repetitions they should do. As stated by Wayne, *"No, she didn't say how much."* Out of the ten participants interviewed, six reported that they received handouts regarding their exercise programs.

In addition to the non-specific recall of the exercise programs, most participants did not report having a strategy for incorporating these exercises into their daily routine. Hannah when asked about how her exercise program fit into her routine she stated, *"Well, it didn't. That's what I'm telling you, it didn't- (short laugh) You know, I get home and I'd get busy being a mom and a… office manager and trying to handle some part of my household…"* Zac stated *"I would say most days they don't."* George reported that he did not have a schedule for this but rather *"it just happened whenever."* Similarly Jennifer stated she *"just made a point of doing it,"* without the mention of a particular schedule. In contrast, Gerald reported that he would complete his routinely, *"After I have my breakfast…I do two hours of exercise."* Wayne also reported a regular routine of certain exercises that were done in the morning and others that were done at night, however given his previous statement this routine was developed independently of a therapist. While participants could relay the exercises and activities they were instructed to do at home, the details regarding the implementation of these exercises for many participants were vague and non-specific, even though half of the participants had received written instructions.

Home exercise programs are independently modified. A second theme surrounding the home exercise programs described by some participants was that they independently modified their home exercise program, making adjustments and changes independent of a therapist. Gerald reported, *"I worked out much of it on my own."* He after not having much success with his home electrical simulation only once a day stated, *"I read up on it [the], research, uh, research procedure. And they had it three times a day"* and reported adding two additional electrical simulation sessions to his routine. Hannah, after being unable to complete her prescribed home exercise program, described how *"…I hired a personal trainer. And, um, so there's this series of exercises… my daughter found on the Internet, the system called G.R.A.S.P. And they said, if I do these levels, I get to three and I'll be able to use my arm and hand."*

While these two examples exemplified the strongest modifications to home programs, other participants reported efforts to find activities that would help with their impairments. Harriet spoke of how she was considering adding a new activity to her routine*: "But see, another thing that I try to do, I go to church every Sunday. And um, they try to um, I've been thinking about it, but not acting on it. I'm still thinking about it. But you have to shake people's hand every week."* Jennifer reported finding a place to continue her work, *"I set myself up in a gym after, um, when therapy ran out … And, um, that gives me a designated place to go to do what I'm supposed to do."* These examples demonstrate that some of our participants changed prescribed programs or found new ones that would work for them as they continued to work toward recovery.

Home exercise programs and barriers. Participants during the course of the pre-intervention interviews reflected useful information on what made it difficult to continue with prescribed home programs. One barrier that was mentioned by several people was the level of frustration that was present as they tried to work on using their upper extremity. Michael stated, *"if you get frustrated and discouraged with what you're trying to do you just won't do it."* When discussing attempting to get dressed Hannah described *"I'll figure it out eventually but that's another thing an' I get so frustrated and then I'm just a ball of tears and…It doesn't seem worthwhile to make myself that upset."* In addition to frustration, Michael also stated *"Fatigue is always a big deal for stroke people"* and that fatigue was something that he factored as to whether or not he did any upper extremity exercises on a given day. Two participants reported pain as a factor that limited home exercise. Hannah stated, “*It hurt to do it so, (puff sound) that was that, I quit.*”

Some participants cited cognitive issues that influenced their participation in home exercise programs such as memory and poor initiation. Mary, when asked about why it had been hard to get an exercise routine going, stated “*Well it’s because I don’t remember… So, I mean, someone has to come over and physically say, ‘Hey, we’re gonna do this.*” Jennifer spoke of difficulty recalling activities that were not written down *“I was boggled by all the information at that time. So, (clears throat) when I was discharged… I didn’t, there wasn’t as much as I thought I remember he had me trying to lift my arm over my head and stuff like that but it wasn’t written.”* Two other participants spoke specifically of the challenges of getting started with home exercise programs. Zac stated, *“I would say, you know, one of my biggest issues it’s, it’s still ongoing really (clears throat) in many facets of my life is initiation… So, just getting myself to get up and go do stuff it’s an ongoing problem. And it’s particularly obvious when it came to those exercises.”* This was further spoken of by Michael who stated, *“…Well another thing, at least for me as a stroke survivor is initiating things sometimes is challenging. So initiating a home exercise session … takes a lot of effort.”*

The above themes illustrate the perception of home programs of the participants in this study based on their previous experiences.

Post-Intervention Interview

Outcome: Neurogame Therapy Experience and Perception. After completing the intervention phase of the study, participants provided feedback on their experience and allowed for insight into Neurogame Therapy acceptability, perceived effectiveness, as well as challenges and suggestions.

Neurogame Therapy Acceptability. Most of the participants in the study found the home program using a gaming interface to be engaging and motivating. For example, Michael stated, *"And it's exciting. I mean, it's really, it gives me uh, adrenaline or endorphin shot when I can do something and, and actually make something happen with my brain with my affected side."* Brad reiterated this feeling more succinctly, *"[The] game just was awesome."* While not all persons were as enthusiastic about the game it was described as "fun," "motivating," and "entertaining." Some participants reported that it was easy to get caught up in the game which made the time pass quickly. Hannah reported that *"And with the game you can get in there and, uh, just get lost in it. And pretty soon you're an hour into it and, uh, you don't think it's an hour. I look at the clock and I think, geez, I've been doing this and I can quit now … it doesn't really feel like physical therapy. It feels like you're playing a game."*

While most participants found the game enjoyable a few expressed different opinions. Wayne reported, *"It's just all pinball."* Harriet shared that *"playing games … just doesn't motivate me. I understood why the purpose of the game and what the benefit of the game but at the same time it wasn't something I enjoyed doing, to be honest with you."* In addition, even some participants who found the game enjoyable suggested that making the game more age appropriate would be beneficial. Jennifer reported *"Yeah. It felt like I was in kindergarten … I mean, then it got harder but it was like my little ponies or something…It's a little dingy, but it was fine I guess. It is what it is."* Wayne suggested that games such as poker or chess would be more engaging to him and required more cognitive abilities.

Although participants had different perspectives on the acceptability of the home gaming program, when asked directly if they would recommend this program to other persons after stroke nine out of ten reported that they would. Mary, was unsure if she would recommend it and stated *"Well if I could see some improvement, which there might be some, but I would recommend it higher."* Participants were also asked when they would recommend this program to other persons after stroke. There was a wide range of responses but most felt that sooner in recovery would be better. While most participants did not identify a number of months out of recovery Michael felt *"… maybe the idea of what the game was about could be introduced within that first year or first six months."* While most participants provided a length of time since incident Zac reported *"…I think, you know, you got to be at a point where you really can move your wrist with consistency."*

Finally, participants were asked about how the program fit into their daily routine. Most participants found the game easy to fit into a part of their daily routine. For instance, Hannah had it setup at the office and reports, *"So it was easy to form a routine about when I would do it because I have a lot of cheerleaders there."* Others, however still struggled to form a consistent routine. As Michael stated, *"I was fairly erratic…Routine for me is difficult just to begin with."* Zac reports how he struggled fitting it in by saying *"So it tended to be sort of trying to squeeze it in around on day when I was pretty busy with two or three other things going on, sort of squeeze around those."*

Neurogame Therapy Perceived Effectiveness. While the game was acceptable to most participants and the majority would recommend it to other persons after stroke, most participants did not report any substantial changes in the function of their impaired upper extremity. Harriet stated, *"I don't think really in the time I've been here that too much has changed."* Wayne after each session was instructed to try to do some typing, he reported, *"I was t-typing…I was trying, but terrible, anyways."* Another participant was unsure if there were changes, as Jennifer reported, *"I don't know how much it improved them…Um, I hope some but I can't tell."*

While most participants did not express visible changes in performance some did report more subtle changes after using the program. Brad reported that compared to previous home programs that this *"was the first time I've got some movement."* Similarly Gerald stated, *"[when playing the game and relaxing]…I feel my hand. Well, I don't know what it's relaxing or what but movement. Things like that…also I have, um, my thumb is starting, well not starting but, when I finish with the game, suddenly, my thumb started [twitching]."* While participants did not experience a change in function a few reported that they felt that they were incorporating their affected upper extremity in daily activities in new ways. Michael who had more severe impairment reported that, *"When one's in a grocery store, pushing a shopping cart, most people do it with both arms or both hands, and so I'm trying now to make sure I rest my affected arm on the (chair slides on ground) shopping cart handle … just at least it would start to emulate or simulate a more normal approach to ADLs."* Similarly Jennifer also reported that she was trying new uses of her affected upper extremity, *"I put on my sweatshirt and my jacket and it there, the sleeve was up above my arm here and it was, like, elastic there so it was kinda stuck up there. And it took me a long time, but I used my hand and stuck it under the elastic and said, well, pull the sleeve and that took me a long time and it's a stupid accomplishment but I thought, it took a lot."* She also reported that she was noticing some differences in how she completed activities she was already doing, for example, *"Well there was like more holding this with my hand when I open 'em instead of pressing it against my body, you know. I was holding it independently with my hand."* However she was unsure if this was due to the game or her workout routine at the gym. George reported that using the game caused him to return to some exercise activity he was doing when he first left the hospital, almost 30 years ago. When asked if participating in the program made him more or less likely to work on his arm he stated *"Uh, more likely 'cause I,* *I've started squeezing a rubber ball more. I've got a fairly good-sized ball that I'm able to squeeze it pretty good."*

Neurogame Therapy: Challenges and Suggestions. During the interview participants also provided us with feedback as to the challenges that they faced when using the home program and suggestions they had for improving it. Each participant encountered at least one instance of a technological malfunction that required troubleshooting. For two of the participants the challenge was following the necessary steps to exit the game and the program interface. Brad stated, *"I didn't turn the computer off and [she] had to come and turn it off."* Another technical challenge participants faced was finding the correct location for the electrodes, which were marked with permanent marker. Participant Mary explains, *"You take a shower and everything goes off."* Charging the Nuerogame box also was difficult for some participants either due to uncertainty if they were charging the box or faulty chargers that did not charge the box.

While most participants faced some technological challenges, other faced challenges such as fatigue, environmental setup, and pain. For example, Jennifer reports that *"I'm really over-worked or over-tired, I find it harder to get the, the strength and finding it."* Environmental challenges were only reported by one participant, Michael, who stated *"I struggled…because I didn't have, uh, I needed, a, a padding on the left armrest on my chair. So I strapped a pillow and things like that but I noticed that, uh, the leads that went from the electrodes to the Neurogame box kind of tended to get tangled…"* Finally, two participants reported that during the use of the game they experienced pain. Hannah reported pain in her shoulder and upper trapezius through pointing but stated that it lasted "*for a couple days and then it calmed down."* The other participant, Jennifer, experienced pain in relation to game play reported *"I played so hard I got my elbow going. And then I hit it out of the chair too*." Neither participant required medical attention nor did these instances prevent them from continued game play.

Participants also provided some suggestions for improving the system from changes to the technology to the implementation of the system. Mary stated, *"I wish [the box] had a, a sensor on it that would tell you if it was high or low or whatever."* Others as previously mentioned suggested that the game should be changed so that it was more age-appropriate or cognitively challenging. Another suggestion made by two participants was that the amount of time that participants used the system should be increased Gerald stated that he wanted *"more time, uh, just, 30 days is not time enough."* Mary concurred with this idea reporting, *"Four weeks might not be enough to see results."* A couple other participants would have liked to see functional use of the arm incorporated into the program. Harriet commented that she would like *"some exercise that would incorporate the use of the fingers so, you know … it should have some more meaning."* Michael thought that collaborating with participants occupational or physical therapist who could provide ideas of *"if I could gain wrist extension I might be able to improve the following things for me individually."* These suggestions provide insight into the ways we can improve Neurogame Therapy for the individuals who may use it.

Discussion

Ten participants completed two one-on-one interviews focusing on topics related to functional use of their impaired upper extremity, previous home exercise, and their experience with the Neurogame Therapy home program. Key themes were identified to highlight the major discussion points for each of the topic areas. Participants when speaking of using their affected upper extremity in activities were able to identify activities that they attempted but reported that these activities occurred infrequently. In addition, participants characterized functional use of the affected upper extremity to be expected as they were instructed on this in their previous therapy experiences although they were not always clear on how to do this. Most participants were provided with home programs in some form although they were often recalled as non-specific suggestions that were independently modified by the participants at varying degrees. Finally, participants discussed their experiences with Neurogame Therapy and shared that the experience for most was enjoyable although they did not notice major changes in the function their affected upper extremity. Finally, the participants provided insight into some of the challenges they faced with Neurogame Therapy and the suggestions they had to improve the home program.

The findings of this qualitative investigation suggest that persons in the chronic phase of stroke understand the importance of and are trying to incorporate the use of their affected limb into daily activities but find that this is challenging. This is consistent with the findings of Barker and Brauer (2005) who reported that persons after stroke understand the importance of continuing to exercise their affected limb but struggle to get started with exercises. Our participants cited barriers that prevented them from engaging in home exercising which included: frustration, fatigue, and cognitive barriers like memory and initiation. This finding suggests that the role of home exercise programs is important not only in extending services but in aiding participants after stroke to continue to work on their upper extremity recovery as they desire.

When discussing participant’s prior home programs while most reported having received instruction on things to do at home, the training that they had received was non-specific. It is possible that the non-specific nature of the home exercise programs made it difficult to incorporate these activities into a daily routine. Furthermore, after participants had stopped receiving direct therapy services it appeared that they developed or modified the routines they were instructed in independent of a rehabilitation professional. This may suggest that home programs require continued monitoring in order to ensure that the exercises are still appropriate for the participant and that the participant is following through and not encountering barriers to implementation.

Participants provided insight into the use of Neurogame Therapy as a home program. This feedback allowed for comparisons between their described previous home exercise programs and Neurogame Therapy. Most participants easily reported how they incorporated Neurogame Therapy into their daily routines, however some described their game play as erratic or unscheduled. It is possible that this difference is an artifact of Neurogame Therapy being part of a study and previous home exercises program being issued in the distant past. Nevertheless it is important to note that some participants were able to incorporate this home program easily into their routines while others struggled due to lack of initiation, poor memory or activities that were too frustrating for them to continue independently.

One notable difference was that most participants reported finding Neurogame Therapy engaging and enjoyable when compared to their previous home programs. In addition, persons found that the time they spent doing Neurogame Therapy passed quickly. While this is positive, only a few participants were able to identify changes in their upper extremity use after using Neurogame Therapy. Some participants remarked on this and suggested that there be a stronger connection to daily activities when using the game and how the movement that was being worked on in NGT could be carried over into other activities. This is consistent with the findings in the quantitative results of this study (Chapter 2), which indicated positive group changes at the level of sEMG but not at the level of functional activity.

Based on the feedback from these participants a few key ideas will be incorporated into future studies of Neurogame Therapy. These concepts may also benefit the implementation of traditional home exercise programs as well. Participants reported that being engaged and successful motivated them to continue with NGT and this appeared to decrease frustration, although not completely eliminate it. Furthermore, the ability to tailor the game appears important as some participants found the game to not be cognitively challenging. As mentioned above adding a strong component of functional activity, as well as, a longer treatment period would potentially strengthen the program and improve carryover into functional tasks. Finally, assisting persons in planning out how they will incorporate this program into their daily routine is critical for follow through especially if persons face cognitive barriers that may make this challenging.

Despite the note worthy nature of some of these findings, one must take into account some limitations of the current study. First the sample was a sample of convenience and relatively small. Furthermore, the perceptions and experiences of this group could be different from the entire stroke population as they were interested in participating in a study. Secondly, several of the participants admitted challenges with memory and therefore their report of their previous home program could have been vague and non-specific due to poor recall and not lack of instruction. For this reason it is important to continue this investigation by speaking with physical and occupational therapists, as well as, caregivers to provide a complete understanding of how a home exercise program functions for persons after stroke.

Conclusion

In summary, our participants, who were adults one to 27 years post stroke resulting in hemiplegia with reported difficulty using one arm/hand for functional activity understood that the use of their affected upper extremity was an important piece to motor recovery, although they found implementing this challenging. Most participants were provided with a home exercise program, and reported some barriers to completing this program regularly. After using

Neurogame Therapy, participants found the program enjoyable, however they encountered new challenges related to the use of the system, as well as, continued cognitive challenges to daily incorporation of the system. While this investigation provides only the viewpoint of the therapy recipients from a small sample, it provides a valuable perspective for researchers and clinicians to consider when developing home exercise programs for adults post stroke.

CHAPTER 4

SUMMARY

There has recently been an increased discussion about the use of mixed research methods in the healthcare literature. The importance of mixed methods in rehabilitation research has been emphasized, given the changing nature of healthcare with more persons receiving services in less controlled environments (Kroll et al., 2005). Mixed methods allow for a combination of both quantitative and qualitative research methods so that that research questions may be answered from multiple perspectives and multiple questions can be answered. These methods can be combined in many ways but must be planned out purposefully (Kroll et al., 2005). The papers in this dissertation detailed the methods and results for a preliminary mixed methods investigation of a home program that utilized sEMG biofeedback through a computer game as a means of providing upper extremity therapy for persons after stroke.

The selection of mixed methods approach was valuable for this study because it allowed for the effectiveness and the acceptability of Neurogame Therapy (NGT) to be thoroughly assessed. A repeated measures quantitative design was chosen to answer questions regarding the effectiveness of the program. Using this design we were able to reduce some threats to internal validity including: history, attrition, and instrumentation. Through this method we investigated how effective the program was by focusing on outcome measures that ranged from co-contraction ratios measured through use of surface electromyography (sEMG) to performance on the Wolf Motor Function Test (WMFT) and Chedoke Arm and Hand Inventory (CAHAI). These measures span two levels of the International Classification of Function (World Health Organization, 2002) by evaluating body function through sEMG and activity performance on the WMFT and CAHAI. While this research design informed our understanding of how the invention impacted outcomes, it did not provide any information on the experience of the intervention as perceived by the participants. For this reason, we included the qualitative piece, which allowed for a detailed look at participants upper extremity use, previous home exercise program experience, as well as the experience and acceptability of NGT. While the qualitative research methods provided insight into the home therapy experience, they did not provide any information regarding effectiveness. The combination of the two research methods in this preliminary study was advantageous as the qualitative results provide insight into the quantitative results based on the experience of the participants.

Combined Results

Nine persons completed the quantitative portion of the study. Overall participants adhered well to the number of home practice sessions requested over the 5 weeks, with only two participants who used NGT at home not reaching twenty sessions. Group analysis found a small but statistically significant decrease in the amount of wrist extension/flexion co-contraction that participants used during a reaching task. While no other statistically significant changes were found, this preliminary evidence suggests that the intervention program is working as intended at the body function level to improve selective muscle activation.

Ten participants finished the qualitative portion of the study and completed interviews at two time points, one pre-intervention and one post-intervention. Through these interviews participants discussed how using their affected upper extremity in daily activities was challenging and infrequent, nevertheless they understood frequent use was a necessary part of recovery. Participants also described their previous home exercise programs in a non-specific way. Furthermore, participants reported that they modified or changed their previous home programs without consultation after being discharged from direct therapy services if they felt it wasn't working or if they wanted new activities. Participants also provided feedback on the NGT intervention with most participants stating it was enjoyable, but only one reported a substantial change in functional use of their hand and arm with the NGT program. However, some participants did report subtle changes in movement patterns and others noted new or renewed awareness and incorporation of their affected upper extremity in daily activities.

When assessing the results from both aspects of the study there are a few key findings. Firstly, it is valuable to note that the quantitative and the qualitative findings were consistent in that participants' performance during the activity tasks and their perception of their functional abilities were similar. However, what was not captured by the quantitative outcomes was that several participants found that they had an increased awareness of their impaired upper extremity and some tried to incorporate using it in new ways. This suggests that while functional performance may not have been affected by the intervention, awareness and attention to the affected limb may have increased. Secondly, the qualitative findings suggest that some participants, while they enjoyed the game, would have liked to see a more direct connection between the game and functional practice. This finding is also consistent with a need for an additional functional component to the NGT therapy program seen in the quantitative study, as participants demonstrated a change mostly on the sEMG outcomes and not the functional outcome measures. The enjoyment of the game as expressed in the participants' interviews was also reflected in the participants' adherence to the protocol. This suggests that the use of a video game increased desire to engage in exercise activity. It is also possible that the decreased frustration and increased success in using their upper extremity also encouraged them to continue with participation. Finally, future studies of NGT will benefit directly from including a qualitative component in order to obtain feedback regarding ease of use of the system, appropriateness of the game, and other suggestions regarding duration and amount of play.

Future Directions

Neurogame Therapy clearly requires further research in order to determine its value as a part of upper extremity rehabilitation after stroke. From this preliminary study there are several follow-up studies that can be conducted that will add, not only to our understanding of NGT, but to the greater body of knowledge on rehabilitation after stroke. These follow-up studies could investigate several questions: (1) Is NGT more effective with a functional activity component? (2) Is NGT feasible for use in the acute phase of stroke recovery? (3) What is the current state of home exercise programs after stroke as viewed by clients, caregivers, and therapists?

In order to investigate the question related to effectiveness with an additional activity component a larger study with modifications to the inclusion criteria (i.e., adding a minimum motor criteria, exclusion of persons with brainstem infarcts, etc.) would be appropriate. This could be done solely as a quantitative investigation, however, with the addition of a new component to the NGT program it may be advantageous to continue with a concurrent mixed methods approach that allows for additional feedback on the new protocol.

The second question stems from the results of the qualitative portion of this preliminary study as participants reported that they thought trying NGT earlier in recovery may have been beneficial. This investigation is also of interest because persons acutely after stroke are in the process of newly relearning how to activate their hemiparetic muscles. This is different from persons with chronic stroke who have already learned one way of activation (co-contraction) and need to unlearn that pattern and establish a new one. While a purely quantitative approach could be used to answer this question, including a qualitative component may allow for insight into the ease of incorporating NGT into inpatient treatment from the perspective of the therapy staff as well as the participants.

The third question also stems from the qualitative portion of this study and calls for a deeper investigation of the nature of home programs. To answer this descriptive procedural question both quantitative and qualitative methods can be used. In order to validate the description of home programming from our participants in a larger sample a sequential mixed method approach could be used to develop a survey based on the qualitative description of home programs. As reported previously there are several stakeholders in the implementation of a home exercise program and we only interviewed one. In order to gain a clearer picture of the nature of home programming qualitative methods could be implemented in order to gain the perspectives of therapists and caregivers.

Conclusion

This mixed methods investigation of NGT allowed for a more in-depth understanding of the effectiveness and acceptability of this innovative home program. The findings were consistent between qualitative and quantitative pieces of the study on perceived effectiveness. Furthermore, qualitative data revealed that participants experienced some subtle changes or had an increased awareness of the affected upper extremity. In addition, the qualitative portion of the study provided insight regarding the acceptability of NGT and changes that participants would like to see with respect to NGT, such as having a direct connection between game play and function. Future directions from this study will aim to investigate the effectiveness of an additional functional activity component; the feasibility of NGT use with persons acutely after stroke and the perspective of therapists and caregivers on the nature of home programs for upper extremity recovery. Mixed methods research can provide valuable information as programs are being developed that may help address issues to the implementation of rehabilitation strategies. Continued application of these methods will benefit our clients, our research, and the broader clinical community.

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Appendix A

Data Reduction

sEMG

These data were processed using software created in LabView. This program first required that the sEMG data and the video recording of the data collection process were synchronized. This was done using a visual signal that flashed when the sEMG recording began. Then the start and end of each task trial was identified using defined visual cues. Data collected during the MVC task were used to determine the MVC level by creating an envelope of activity using a very low pass (0.5 Hz), 8^{th} order Butterworth filter, which was applied to the rectified, null-offset sEMG signal. The 5 MVC trials for flexion and for extension were calculated and averaged to provide the MVC level for that assessment. Only eight participants had complete data for wrist extensor MVC and only seven for wrist flexor MVC due to technical malfunctions.

The sEMG signal for determining timing and amplitude parameters (except MVC levels) were rectified and low pass filtered using a forward and reverse pass Butterworth filter at a default frequency of 20 Hz and order of 4 per pass. To determine the amount of sEMG co-contraction the signal's onset and termination were determined using an automated threshold level. The Threshold Method was applied after filtering without further integration of the signal. The threshold of the quiescent data level was set above (Threshold Multiplier) x (mean + n x SD of quiescent level). Quiet events with durations less than the "quiet limit" were not used in determining onset and termination. Events beginning or ending above the threshold were ignored. To calculate co-contraction the integrated signal for the agonist was divided by the integrated signal for the antagonist, over the period of agonist activity. In order to control for potential variability in the placement of electrodes and participants' daily variability in performance the co-contraction ratios were normalized using the mean MVC level for wrist flexors and extensors calculated from the MVC task for each participant. To do this the integrated agonist was divided by the agonist mean MVC level over the integrated antagonist divided by the antagonist mean MVC level. Again only eight participants had complete data for this variable. The participants with previously missing data were included using MVC data from the other available baseline pretest to normalize the co-contraction ratios for both pre-tests. A second participant had erroneous data for the reaching and active wrist extension tasks, possibly due to a loose electrode and therefore his second test data was not included in the group analysis.

Kinematics

After data collection markers were identified and files were exported for analysis within a custom LabView program. Using the 3rd metacarpal marker as the metacarpal of interest the number of repetitions was identified. Then each trial's start and finish were visually identified using the Qualsys Track Manager program, at the first sight of movement of the 3rd metacarpal marker the time was noted. The variables of interest during the drinking task were reach time and number of movement segments during the reach phase. Reach time was calculated as the time from the start of movement at the 3rd metacarpal that was greater than 2% of the maximal velocity until the cup was moved a minimum of 2 mm from it's starting position (the average of the first 100 frames of data). The number of movement segments was calculated by first identifying the minimum and maximum velocity for the hand marker during the reach phase. Velocity peaks were then identified as the difference between a minimum velocity and the next maximum velocity that was equal to or greater than 20 mm/s that occurred at least 150 ms after the prior peak. The number of velocity peaks that met these criteria was considered the number of movement segments.

Appendix B

Graphs Used for Individual Visual Analysis

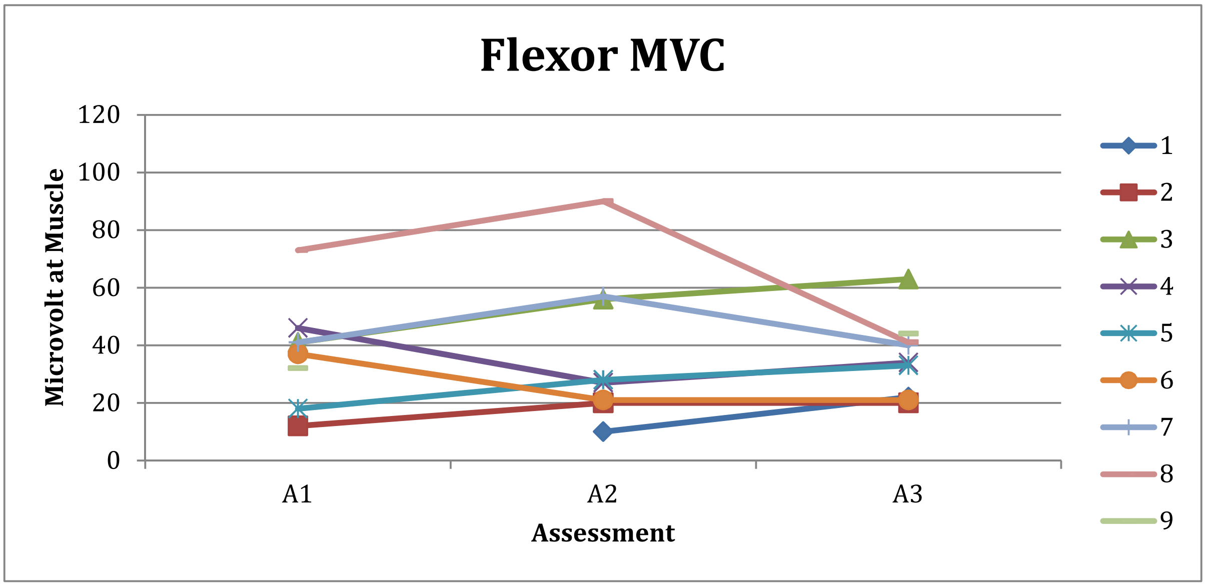

Figure B1. Graph of Performance on Flexor Maximal Voluntary Contraction (MVC)

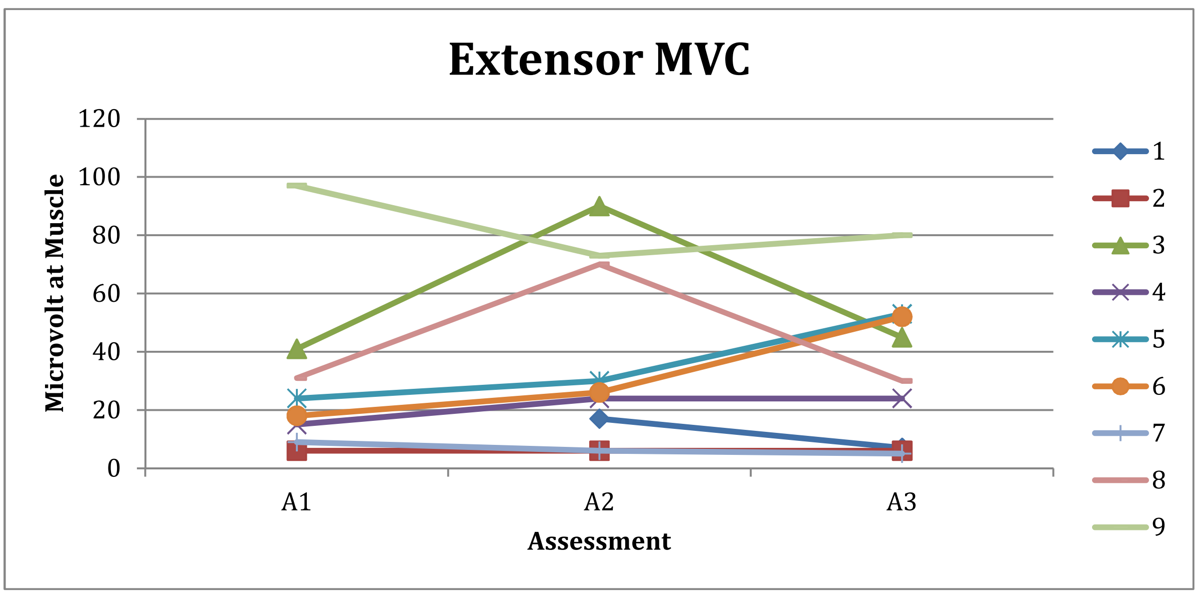

Figure B2. Graph of Performance on Extensor Maximal Voluntary Contraction (MVC)

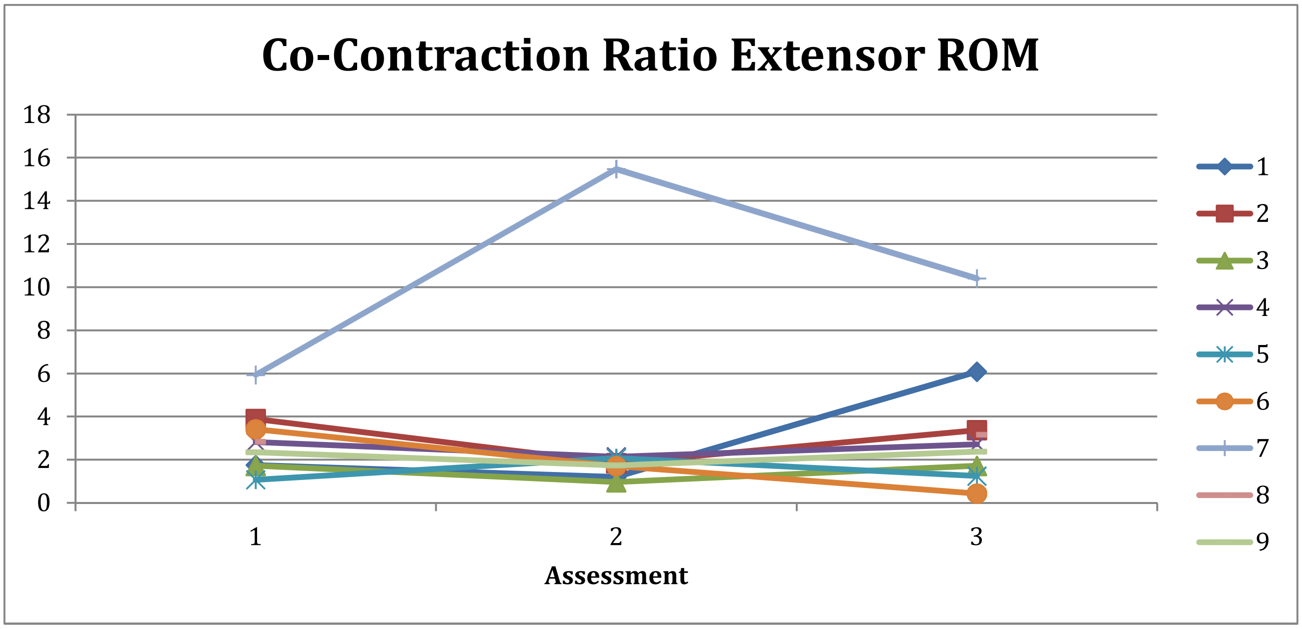

Figure B3. Graph of Co-contraction Ratios for Extensor Range of Motion

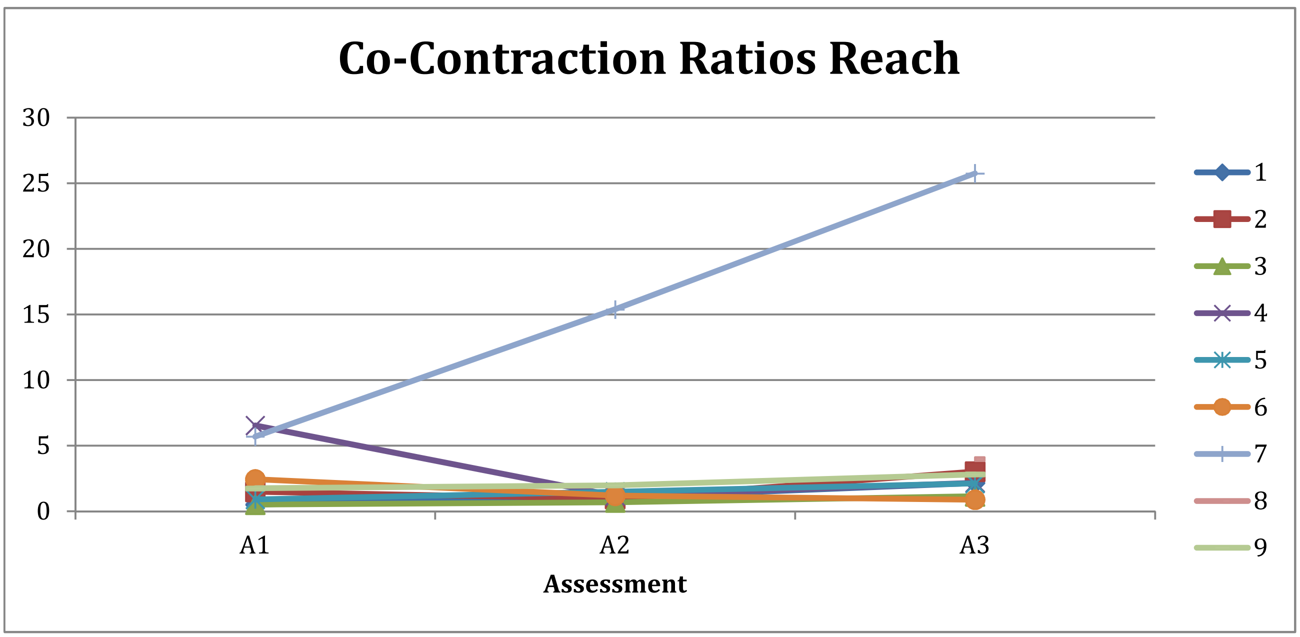

Figure B4. Graph of Co-contraction Ratios for Reach Task

Kinematic Graphs

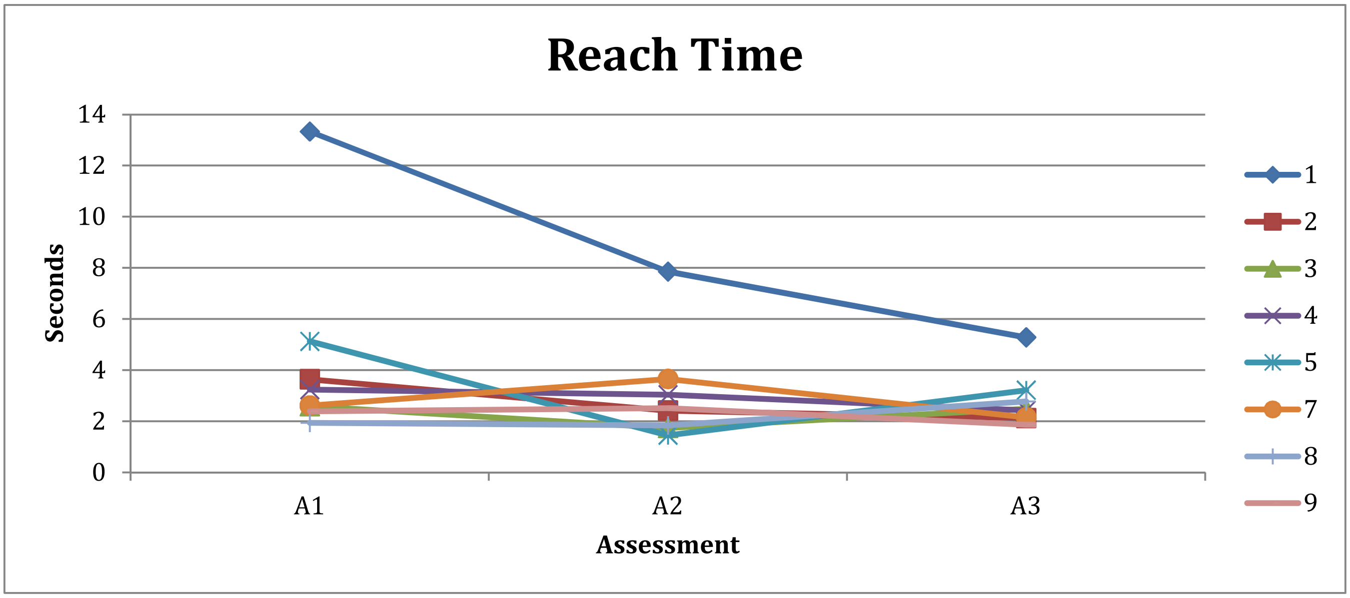

Figure B5. Graph of Total Reach Time During Reach Task

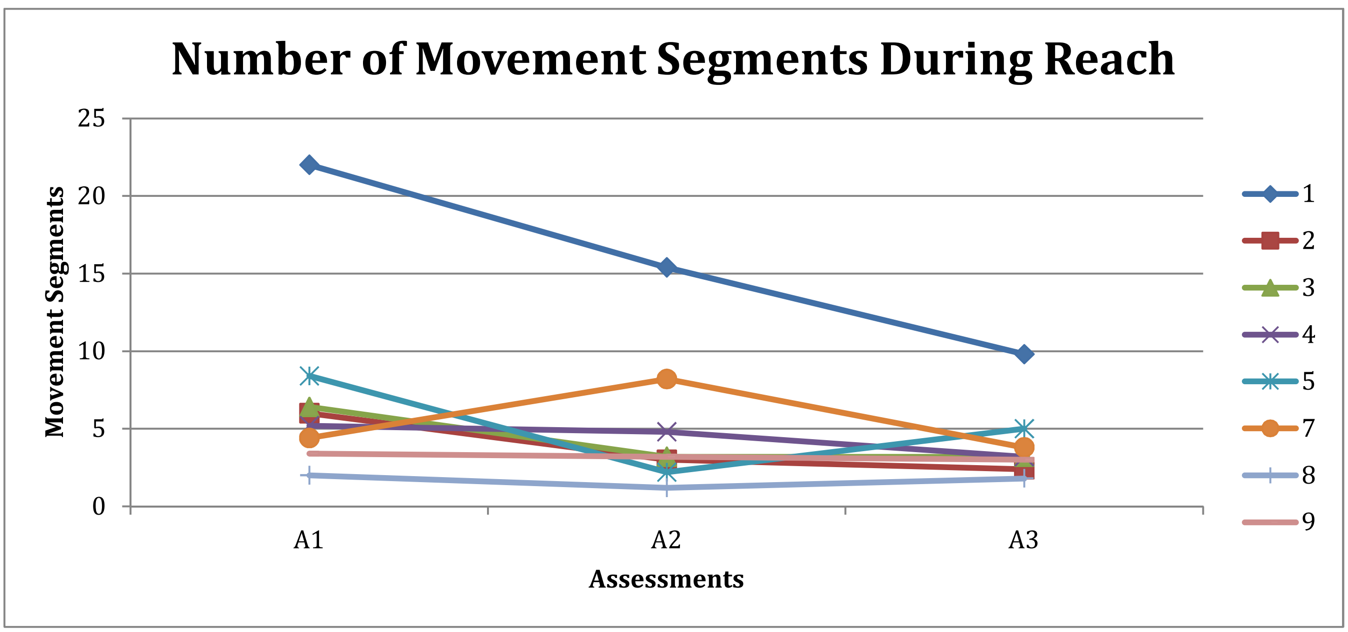

Figure B6. Graph of Number of Movement Segments During Reach Task

Activity Measures

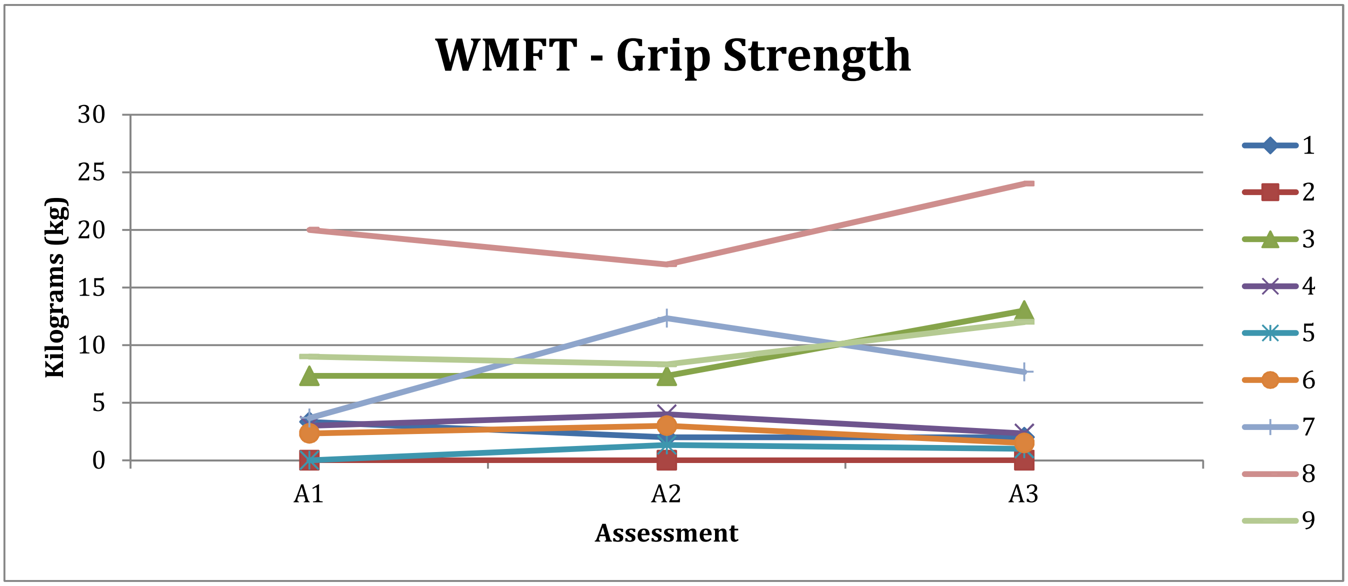

Figure B7. Graph of Grip Strength in Kilograms on the Wolf Motor Function Test

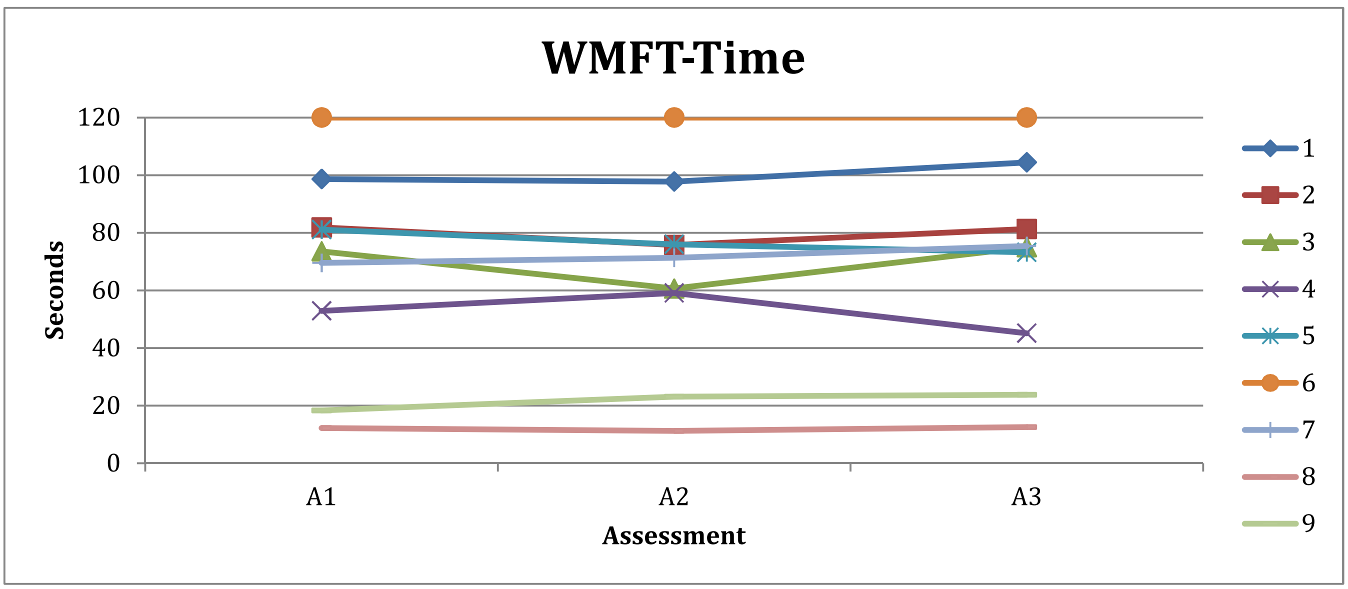

Figure B8. Graph of Average Time to Completion in Seconds on the Wolf Motor Function Test

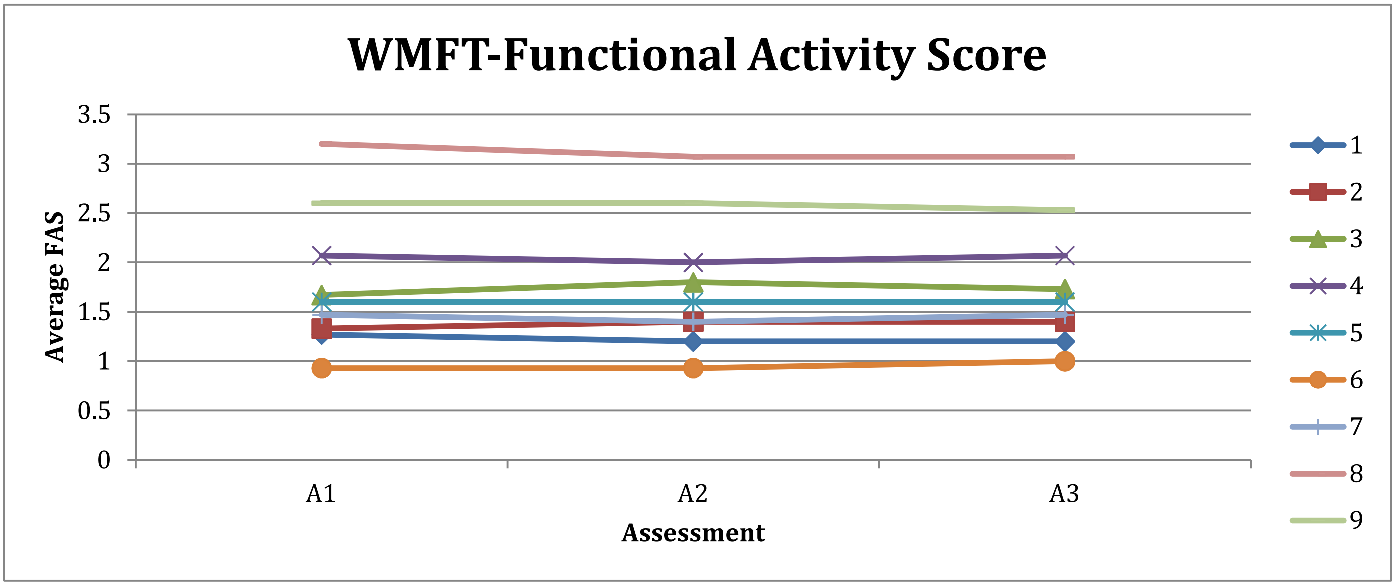

Figure B9. Graph of Functional Activity Scores on the Wolf Motor Function Test

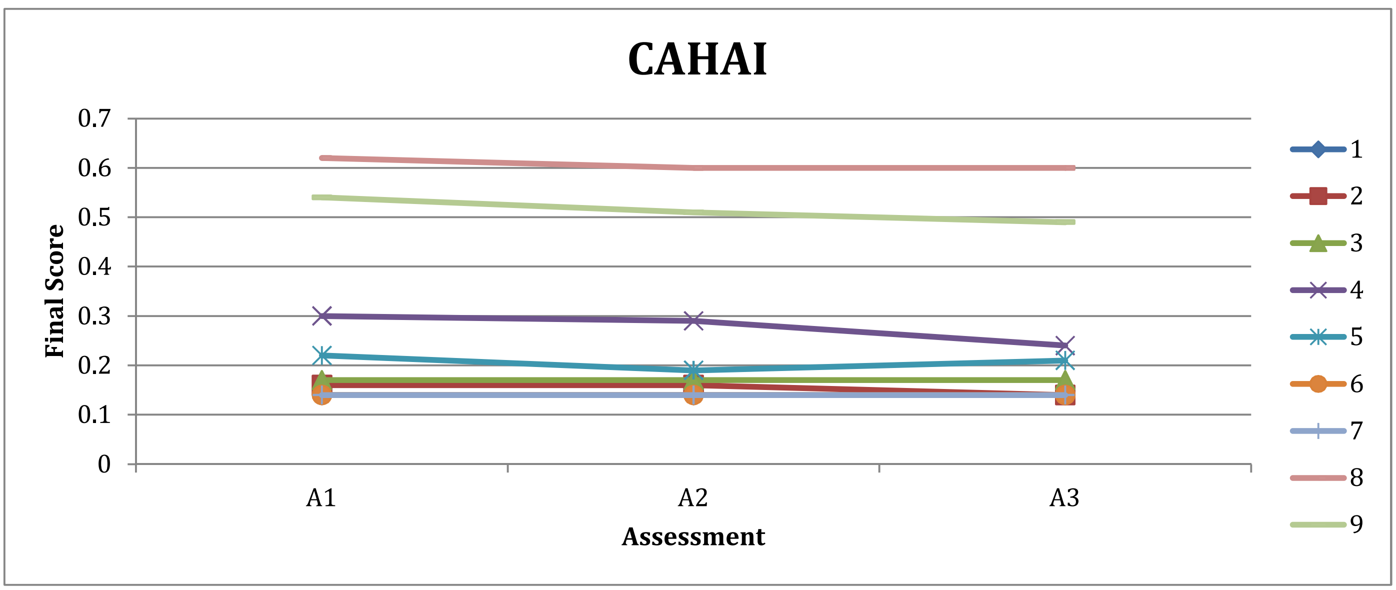

Figure B10. Graph of Percent Scores on the Chedoke Arm and Hand Activity Inventory

Appendix C

Semi-Structured Interview Guide for One-on-one Interviews

<u>Pre Intervention Questions</u>

How do you use your affected arm in daily activities? Like taking care of yourself? Doing chores around the house?

- What efforts do you make to use your arm during the day?
- How successful are you in your attempt to use your arm?
- What activities do you use your affected arm in *most often* at home?
- What activities are you *least likely* to use your affected arm in at home?

Tell me about any home exercise or therapy programs you have used since your stroke to help your arm?

- How were home therapy suggestions presented to you? Handouts? Video? Verbal instructions or actual demonstrations?
- Of those suggestions what were you able to do at home and what did you have more difficulty doing?
- How did these therapy suggestions fit in to your routine at home?
- What did you like about your previous home program(s)?
- What did you dislike, if anything, about your previous home program(s)?

What are you looking to gain from this intervention study that may be different from what you have tried in the past?

In a typical day how would you describe your use of technology? (i.e., computers, telephones, video game systems, e-readers, smartphones, etc.)

You mentioned [name the technology that was mentioned], how many hours a day would you say you spend on the [name technology above]?
(Repeat for the number of pieces mentioned)

How often would you say you play video games each week, or month?

<u>Post Intervention Questions</u>

Tell me about using the computer game system over the last month.

- What are some things that helped you use the system at home?
- What are some things that limited your use of the system at home?
- How did use of the system actually fit into your daily routine or schedule?

How would you describe the training you received prior to bringing the gaming system home to use?

- Any recommended changes in the training process?
- What technical problems, if any, did you have using the gaming device?

What would you suggest changing about the intervention?

Tell me about how you described the intervention to someone in your family, or to friends?

Would you recommend this approach to others, such as other people with stroke? Why or why not?

When in your recovery do you think would be the best time for a computer-game like this?

Compared to your previous experiences with home exercise or therapy programs (provide examples from pre-intervention interview)

- How was this different?
- How was this similar?

Did the use of game-technology in the exercise program make it more or less appealing to spend the time working on using your arm?

What differences, if any have you noticed in how you use your arm since using the game for the last month?

How do you use your affected arm in daily activities? Like taking care of yourself? Doing chores around the house?

- What efforts do you make to use your arm during the day?
- How successful are you in your attempt to use your arm?
- What activities do you use your affected arm in *most often* at home?
- What activities are you *least likely* to use your affected arm in at home?

Appendix D
Coding Structure for Qualitative Data Analysis

Pre-Interview Codes

Functional use of affected arm – a description of how the arm is used in daily life

Attitude – comments on how a person feels or thinks about the affected extremity, as well as, a persons thoughts on recovery

Prior therapy – any description of prior therapy that was completed with a therapist

Prior home activities/exercises – any description of activities or exercises persons were instructed to do at home on their own

Delivery of home programs – a description of the manner in which persons were given instructions to aid in completion of home exercises/ activities

Expectations for participation – any description of what a participant was hoping to gain from participation in the study

Satisfaction with home programs – any description of likes or dislikes related to home programs, as well as general feelings regarding the use of a home program

Technology Use – any description/naming of what technology a persons uses regularly

Amount of Use – any description of how long they use the above technology

Exercise and daily routine – any description of how the participants approached incorporating home exercises into daily routines

Barriers to home exercise – thoughts or feelings on what made it difficult to do home exercises or activities

Post interview Codes

Perception of NGT – any description of the game or their experience using the game

Perception of Effectiveness – any thoughts or feelings on how the game made or didn't make changes

Challenges – problems or technical difficulties encountered when using the game also barriers to using the game at home

Daily routine – description or report of NGT incorporation into daily activity, use of scheduling techniques

Perception of Training – comments on the adequacy of training prior to using the game independently at home.

Suggested Changes – any suggestions or feedback that participants gave regarding how to adjust, change, or improve the NGT

Recommendation – participants' thoughts on others with using NGT and timing

Compared to previous – Any comparisons that were made to previous forms of therapy and the use of NGT how they were similar or different

Functional use of arm – Any descriptions of the functional use of their arm after NGT

Expectations - descriptions of how they expected NGT to work or their study participation or changes in the use of their extremity

Incorporating use of hand – comments on incorporating more the use of hand in NGT

Previous Therapy – description of previous therapy

Facilitators – things that helped persons use the game at home

Appendix E
Participant Descriptions of Functional Activities and Home Exercise Programs

Table E1

Participant Descriptions of Functional Activities and Home Exercise Programs

Participant	Functional Activities Named	Home Exercise/Activity Program Description
Michael	"*I tend to use it as a paper weight basically, to try to hold things down*."	"*at the behest of my OT, I try to turn on and off light switches with that arm*" "*I have a few exercises I do at home… OT exercises. Like if I can get my hand open - I have a lot of spasticity - then I try to get it around the refrigerator door and open and close that to a metronome For like 5 minutes."* "*There are some exercises I try to do laying, I'm prone, on my back, and I try to… just h-just have my arm resting on it's elbow and try to maintain a vertical… I don't know how you describe that*."
Mary	"*I can lift if up like this…And, I can push it out as long as I use this arm… I really can't do a whole lot with it though. I can't you know get a cup or anything like that*"	"*I'm supposed to like, with my cane, lift up*." "*But…I didn't do any OT stuff with my arm…But I did some PT stuff and I'd have to have my mother or mother-in-law come over and do it with me…And I did do some stim stuff."*
Gerald	"*Um, I can turn, uh, turn the light switch on (short laugh) and off*" "*I can use the, uh, I can use the thing, th-um, the bag so that I can put it in there… And then I can just go down stairs and up stairs…laundry go downstairs*." "*oh my, my hand is like a club. So I can turn on the water here, here*."	"*shrugging my shoulder*" "*And then I go and work out here and here… And I do that about 10 times*" "*And then, this one right here, the bicep, um, biceps, um, anyway, you're- you're going to here and here. But, um, I don't, I, I, um, do-don't do it very much*" "*And (sigh) then we've got to get my elbow and my, put the hands up there and I use, again… Um, I can do weights or not, and so, depends about how my grip is*" "*And then (clears throat) (chair shuffling) my (clears throat) (sigh) Okay, now it's going to go this way, this way, or this way (sliding*

		noise)" [Participant is describing active range of motion on the table top with a towel.] "*And then (clears throat) my [fingers out]*" "*And then I put on my electrodes… the morning and then the lunch and then at noon.*" "*…in the evening I can, um, I've got those little things that, um, it's uh gel, gel or something like that. It's a ball*"
Harriet	"*I have tried to use it with opening doors or hanging- using it to hang up clothes. Um, to han- um… deal with putting clothes in the basket or washing and picking up the basket to (sigh) bring the clothes, um, upstairs."*	"*Yeah this, this kinda exercise*" [Participant is demonstrating bending her elbow] "*Yeah and um, I ha- I had a thing that I put on my, um, thumb to stretch it out. That I used to stretch out my thumb*." " *I had this device that I had on my arm. And it would stimulate the muscles in my arm*" "*… we had a lot of exercises with opening doors and refrigerators and turning on the lights. You know, things like that*"
Jennifer	"*Like I can rip up paper towels and stuff like that finally*." "*I can hold jars when I'm scooping stuff out*" "*I hold it when I wash dishes. I can hold a glass and, and wash around instead of chasing it around the sink*." "*I help pul- like, hold on when I'm hanging up a coat or something I can hold the hanger*." "*I hold it when I do laundry. And I use it when I do laundry*." "*I can carry a bag with this hand too and sometimes I do that but, not all the time. Depending on how heavy it is*."	" '*Cause she kind of gives me stuff to do… She did the hand thing and I did blocks with her. And one of the exercises she told me was picking up a book and just turning it kind of and holding on to it with both hands*" "*Um, and then she, we worked about the relaxing and stuff and how to make, push down on the arm to relax*." "*I did it [electrical stimulation] with my wrist coming- first I did pushing down… Straightening my arm. And I did on my shoulder, kind of… And then I did it on my wrist too…So down here. And then my wrist would back and forth*."
Hannah	"*I try at work to um, shut off lights with my… I don't do much else with it."* "*I'll have to grab a hold of something to balance myself. And um, if I concentrate on using my arm then… but sometimes it just works*."	"*So I hired a personal trainer. And, um, so there's this series of exercises, you probably know all about this, called grasp.* *And they said, if I do these levels, I get to three and I'll be able to use my arm and hand*."

		"*I cut…putty with a knife last week.*" "*Um, I hold a washcloth and turn my wrist back and forth.*" "*Now the next level is putting my hand on a chair and trying to push myself off with that*." "*And then I do this thing with my arms straight up with all kinds of weights on it*." "*One is putting my elbow on the table and bringing my arm up and down like that*."
Brad	"*…I- I get dressed… Two hands*" "*And I turn off the lights*." "*…right hand is doing dishes…My left hand is doing it and my right hand is doing it*." [Participant describes holding dish with impaired upper extremity and wiping with other] "*Cutting cheese*" [Participant describes with interviewer impaired upper extremity holding the cheese] Participant also described using impaired extremity as a stabilizer with opening jars, bottles of wine and holding a fork during cutting. "*Doorknobs, yeah*"	Participant demonstrated the following and they are described by the interviewer as follows: "Because you were telling me that you really like to straighten your hands, your fingers, your wrist" "So you're using your left hand to help straighten your elbow and shoulder in front of you. … And then pulling your right shoulder back and across your body. And lifting your shoulder up it looks like. "
Zac	"*I try and use it for door handles fairly regularly, or elevator buttons.*" "*Like I've gotten so I can open most of my pill bottles*" "*Um sometimes if I'm getting ready to do a load of laundry I'll use the left arm to hold, partially hold the pile when I'm carrying it from one room to another*." "*I do use it to, um… hold and press on like the shaving cream.*" "*I use it a little bit. Mostly with shirts and a*	"*…Stacking cups and un-stacking cups, um, what else? Putty manipulation…*"

	little bit with pants.”	
Wayne	Participant described and demonstrated the following to the interviewer with yes/no responses to confirm description: “taking a pill” “able to help with buttons” “putting your shirt on” “Yeah you can open your hand to hold the bottle” “open a jar” “With your right hand to do all the grooming on the left side of your body” “And then your right hand is still helping …To hold the vacuum” “The dishes in your right hand…and then you’re drying off with your left.” “Laundry” “Hoe. Yep. Okay. And when you’re doing …the left is like leading. And the right is still supporting and helping and guide” “with weeding you’re more taking your body weight into your right hand” “Carrying the [garbage] can” “So your right hand can squeeze the handle on the electric mower”	Participant demonstrated the following and they are described by the interviewer as follows: “You’re doing some exercises for your lower legs…” “Squats” “Okay so you were practicing getting up from the floor with your legs” “push-ups” “laying on your belly” “And then you reach your arm forward and to the side” “So lots of strengthening for your arm and range of motion it sounds like” “And then at night… Oh digi-flex” “Something similar…That you flex your fingers on.” “Then you’re also squeezing a ball” “Weights and bikes at the YMCA”

George	"*I use it when bathing*" "*I use my left hand, left arm to help pull up my pants*." "*I use my left arm for putting on my shirts and stuff like that.*" "*I can grab the, grab the whole both of them so I can zip.*" "*I can't other than just stab it with a fork and then cut with a knife*." "*Pears or nectarines and stuff, I can hold it with my left hand and then it's- cut it with my right*." "*Uh, I normally will hold the jar with the left hand and unscrew with the right*." "*Uh, I do all the, the dishes very simple because I just, I can pick up any dish and stuff like that with the left hand, but I do all the washing with the right.*"	"*for the hand I just squeezed a rubber ball*"