Neuromotor Control Differences in the Upper Extremity Between Those With and Without Rheumatoid Arthritis

by

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TABLE OF CONTENTS

Abstract:

Rheumatoid Arthritis (RA) causes inflamed synovial membranes that can affect functional ADL's, motor performance, and neuromotor control. The constraints of RA limit the range of motion and functionality of the upper extremity, which will influence movement patterns and potentially modify neural processing. The purpose of this study was to assess neuromotor control differences in the upper extremity between those with and without RA. Using brain activity measurement and motion capture, we expected to find that RA patients perform less accurate movements and adopt different movement patterns than healthy controls. Further, we hypothesized RA participants would have increased neural processing within the frontal cortex. Ten healthy controls and one RA patient completed eight trial blocks manipulating fifteen marbles of varying size. All participants had their brain activity assessed through EEG and fine motor performance measured via Vicon Nexus motion capture system. Results were expected to demonstrate changes in theta and alpha power and to correlate with restricted movements in RA patients. Results showed a significantly reduced elbow joint angle among the RA participant and higher levels of brain activation for both the small and large marble manipulation. Qualitative compensatory actions were observed in the RA participant's movements. The young and middle-aged healthy controls explored a greater degree of change at the elbow for both marble sizes. Additionally, the young healthy control experienced the lowest brain activation throughout the trials and the middle-aged control had a brain activation between that of the young control and RA patient. Overall, the results demonstrate the use of EEG as an effective tool to measure cognitive workload in RA patients while performing fine motor tasks.

Introduction:

Rheumatoid arthritis (RA) is an autoimmune disorder that directly affects the tissues that line joints, resulting in thick and inflamed synovial membranes. The aftermath of rheumatoid arthritis includes joint erosion and degradation, swelling, pain, and deformities that negatively affect neuromotor outcomes and functional capabilities. Rheumatoid arthritis commonly affects individuals aged 30 to 60 years of age with expression seen three times more often in women than men (Freeman, 2018). "Arthritis-Related Statistics" (2018) discloses that as the population ages, arthritis diagnoses are expected to increase exponentially with a projected 78 million by 2040. This statistic accounts for roughly 26% of the United States adults, indicating the growing emphasis and understanding that must be placed on the disease. This study aims to uncover more on how RA affects motor capabilities and neural communication within the upper extremity, so that reduced functionality may be better managed in the future.

Rheumatoid arthritis negatively affects the joints in both the upper and lower extremities and may lead to disability and reduced functionality. Commonly, the proximal interphalangeal (PIP) and metacarpophalangeal (MCP) joints in the hands and wrists, as well as, the metatarsophalangeal (MTP) joints in the feet are depleted due to RA (Ruffing & Birmingham, 2020). Other areas of the extremities are affected including, but not limited to, the ankles, knees, elbows, and shoulders. Typically, RA affects the joints of the hand first, which is why this study focuses on compensatory movements of the upper extremity specifically. The physical deterrents that RA patients experience affect their motivation and ability to safely complete activities of daily living (Dellhag & Bjelle., 1999). Studies of this nature to neuromotor control differences due to RA onset are crucial to further assess impacts quality of life, progression of symptoms, and treatment options (Palamar et al., 2017).

My great-grandmother suffers from rheumatoid arthritis and has experienced reduced functionality due to the deformation of her hands and fingers. Her experiences have sparked my interest in a study of this nature to evaluate the degree at which rheumatoid arthritis affects motor performance and to investigate any connectivity changes that occur within motor units. Further, I am pursuing a doctorate in occupational therapy next fall. As an occupational therapist, I anticipate researching and working with patients who experience fine motor deficits due to diseases such as rheumatoid arthritis.

Purpose:

The primary purpose of this study was to assess neuromotor control differences in the upper extremity between those with and without rheumatoid arthritis. A secondary purpose for this research was to understand neuromotor control of RA patients. Upper extremity functionality is essential for engagement in daily activities of human life and in the field of occupational therapy. There is a current lack of in-depth research on RA's effects on motor performance. This study aimed to report information on RA's influence on neural connectivity and motor performance outcomes so that therapeutic techniques may be developed to combat declining functionality associated with RA.

Research Questions/Hypotheses:

Given the specific aim of this project was to assess neuromotor control differences in the upper extremity for rheumatoid arthritis patients, the guiding question for this research was "Are there neuromotor control differences in the upper extremity between RA patients and healthy controls and to what extent do these differences affect motor performance in RA clients?"

I had several hypotheses for the outcomes of this research study. First, I hypothesized that RA patients would perform less accurate movements. Additionally, I predicted that the rheumatoid arthritis patient would experience greater processing within the frontal cortex for both the small and large marble sizes. The frontal cortex houses an executive system that is important for sequencing, planning, and decisions regarding movement. The constraints of RA, such as joint pain and inflammation, limit the range of motion and functionality of the upper extremity. For this reason, I hypothesized that RA will influence RA participants' movement patterns through compensatory actions thus increasing neural activity or processing in the frontal cortex.

Review of Literature/Background:

Rheumatoid arthritis is a multi-faceted disease with far-reaching effects on those who are diagnosed. RA participants' neuromotor performance is affected by the symptoms of RA, neural and cognitive processing, and motivational factors. RA patients' quality of life is heavily influenced by the joint pain, deformity, and disability they experience due to declining functionality. The following is the review of current literature that denotes the debilitating outcomes and reviewed findings of RA that are applicable to the information presented within this study.

There is currently limited research on the effects of RA on motor performance outcomes; however, the authors of "Motor Performance of the Hand in Patients with Rheumatoid Arthritis" discussed that rheumatoid arthritis negatively affects motor outcomes and capabilities (Kauranen, Vuoutikka, & Hakala, 2000). Specifically, the study reported that reaction and movement times may be influenced by RA, especially in multi-joint movements. According to

Hick's Law, as the number of choices for response increases, the amount of reaction time linearly increases. Both simple and choice reaction times were reported as being much longer in RA patients than in the healthy controls. The constraints of RA including deformity and joint deterioration restrict movement capabilities further. The constraints of the task may also cause RA patients to adapt different motor patterns through compensatory action to achieve the goal or solve the movement problem (Simonsen et al., 2019). Fear of joint pain and inflammation were also decided to have prevented some subjects from performing movements as quickly as healthy individuals.

The effects of RA are on the upper extremity, hand, and wrist have been continually researched in the past. The consensus is that RA causes joint deformity and disability of the upper extremity limiting function, dexterity, and activity engagement (Erol et al., 2016; Palamar et al., 2017). The disability experienced by a quarter of RA participants is a result of joint deformity (Scott et al., 2000). RA related hand performance and capability is one of the primary factors affecting patients' disease-related outcomes (Bodur et al., 2006). The effects of RA on motor outcomes are extensive affecting multiple motor outcomes such as range of motion, grip strength, and coordination. For example, Erol et al. (2016) found that RA has detrimental impacts on movements at the hand. RA participants had substantially lower scores on the standardized Purdue Pegboard tests indicating a poorer range of motion (ROM) and fine dexterity. Joint range of motion is especially important for RA patients as their joints deform and deteriorate. Optimal joint ROM ensures the ability to engage in everyday occupations and function independently (Nolte & Janse, 2013). ROM has been noted to constrain RA patients as their disease progresses. More specifically, ROM at the wrists and fingers joints drastically declines as the disease advances (Erol et al., 2016). Goodson et al. (2007) found similar trends of

reduced grip strength and range of motion among their study's RA participants. Further, their results indicated a strong correlation between RA participants' range of motion, level of disability, and time since diagnosis (Goodson et al., 2007). Additionally, Dellhag & Bjelle (1999) reported that RA hand functions and impairments, such as grip strength, progressively worsen or plateau without improvement over long periods. The worsening of symptoms can contribute to a lower quality of life and independent performance (Sharma et al., 2004). Moreover, grip strength assessments have been proven to reveal upper extremity functionality and capabilities within the RA population. This indicates that therapeutic techniques may need to focus on maintaining handgrip in RA patients to promote activity of daily living engagement (Adams et al., 2004).

Joint deformity and disability measures of RA patients have also been shown to impact dexterity in movement patterns and neuromotor outcomes in terms of compensatory movements. Erol et al. reported in 2016 that finger and wrist joint disability, which leads to the crippling of the hands, affects nine out of ten RA patients. Barbier et al. (1999) explained that RA patients with and without medical joint stabilization surgeries have deteriorated upper extremity function according to their Purdue Pegboard Test scores. While this particular study aimed at assessing wrist fusion surgeries, they observed that RA participants use compensatory actions throughout the upper extremity. Specifically, compensation was seen at the ipsilateral shoulder and elbow when RA participants' wrist function had been negatively impacted (Barbier et al., 1999). Further, Sharma et. al (2004) noted the future importance of evaluating compensatory movements in RA patients. They emphasized that future research implications should assess the locations of the upper extremity that exhibit compensatory actions when hand deformity occurs in RA patients. Compensatory movements have also been found in the lower extremity of RA

patients with balance and gait studies (Ekdahl & Andersson, 2009). For example, when the tibialis posterior muscle was impaired in RA patients, muscle recruitment of the muscle was naturally reduced in response to pain. Other muscles such as the flexor digitorum longus and flexor hallucis longus were recruited more to compensate for the experienced pain (Simonsen et al., 2019). Additionally, the force generated across the ankle joint was heightened in response to the muscle's deficiency in power. This shows that the central nervous system acted through recruitment patterns to compensate for the constraints of the injured RA patient (Simonsen et al., 2019). Interestingly, RA patients denote pain, fatigue, joint stiffness or tenderness, and reduced functionality as factors that limit their mobility (Van Zanten et al., 2015; Qvarfordt et al., 2019). The above findings of Simonsen et al. (2019) indicate the compensation of motor performance through neural mechanisms.

Several studies have previously reported the cognitive and central nervous system impacts associated with rheumatoid arthritis. Kauranen et. al (2000) also noted neuromuscular differences between RA patients and healthy controls. For example, the researchers described that RA can affect neural function and degenerate fast-twitch or type two muscle fibers. Atrophy of type two fibers declines force production and speed in movement. For this reason, slower movement times and poor coordination are associated with RA (Kauranen, Vuoutikka, & Hakala, 2000). More complex movements require more processing in the frontal cortex and changes in response execution. EEG is utilized to portray whether RA patients experience more processing in the frontal cortex than healthy controls. Bartolini et al. (2002) and Wartolowska et al., (2019) reported altered brain structures as possibly affecting neuromotor performance in RA patients. Bartolini et al. (2002) studied motor outcomes for RA patients with intentions of linking altered performance to cognitive alterations due to RA. The results portrayed that more than a

third of RA patients exhibited complications related to psychological plasticity. A significant deficiency was evident during the completion of visual-spatial tasks requiring neural processing and integration for motor achievements. Almost three-fourths of participants experienced disability in these types of tasks (Bartolini et al., 2002). The study utilized magnetic resonance imaging (MRI) to conclude that lowered blood supply to the frontal and parietal lobes or loss of connectivity between myelinated fibers below the cortex and the frontal and parietal lobes may be responsible for lowered neuromotor control in RA participants. Lastly, the study indicated that deteriorated joints could become less sensitive to sensory input altering neural processing and consequently cognitive planning of movements (Bartolini et al., 2002). Wartolowska et al., (2019) found an abundance of gray matter in the basal nuclei outside of the brain cortex and no changes within the outer cerebral cortex of RA participants. Interestingly, the basal ganglia affect motor performance and neuromotor control outcomes. The results of their study may be useful to link neuromotor deficiencies to neural connectivity alterations (Wartolowska et al., 2019). Moreover, Azeez et al. (2020) cited cognitive impairments that negatively affect daily functioning and the ability to control modifiable risk factors of RA.

RA has far-reaching impacts outside of motor performance alone. Motivational influences affect performance outcomes of motor activities among RA patients. The physiological pain and lowered affective state patients naturally adopt due to their degenerative disease may lessen their already low exercise motivation and self-efficacy. Self-efficacy can affect motivation, effort, and workload when solving movement problems. Knittle et al. (2011) studied self-efficacy related to motor activities and physical exercise. The results implicated that higher self-efficacy and autonomous motivation among RA patients have been linked to an increase in physical activity and consequently motor achievements. For this reason, RA

interventions have been developed that focus on increasing self-efficacy in RA patients through individual goal setting and mastery experiences. The results of the study showed that higher self-efficacy indirectly affected arthritis pain and directly influenced mental and physical QOL. Self-efficacy was also concluded to have an indirect effect on arthritis pain through goal achievement and overcoming the movement problem. Patients with high self-efficacy are likely to set higher performance goals which may be more strenuous, ultimately relieving arthritis pain. Lastly, it was found that overcoming movement problems through the achievement of goals impacts QOL outcomes for RA patients. This may be due to the achievement of goals increasing their sense of perceived control over their disease (Knittle et al., 2011).

Methodology:

Participants:

A total of ten participants completed this study protocol. Participants were recruited using word of mouth, email advertisements, and flyers with information. One participant was an eighty-three-year-old rheumatoid arthritis patient who was clinically diagnosed with rheumatoid arthritis. The RA patient met the study's inclusion criteria as the participant is currently receiving pharmacological or therapeutic treatments for RA symptoms. Additionally, the participant did not have any comorbidities that affected their motor outcomes or cognitive capabilities. More specifically, the RA participant had not been previously diagnosed with a stroke, Parkinson's, or Multiple Sclerosis. A fifty-two-year-old middle-aged healthy control also completed all trials. The remainder of the participants were eight young healthy controls with an age range of eighteen to twenty-two years of age and an average age of twenty years. All participants were screened and required to use the proper personal protective equipment including masks and

regular sanitation to ensure safety throughout the procedure. In the future, as more participants completed the study, RA patients will vary in degree of functionality within the upper extremities due to rheumatoid arthritis expression.

Equipment:

Compumedics QuikCell (EEG cap sponges) will be utilized to monitor neural connectivity and brain activity throughout the completion of the novel marble tasks. Neuroscan 64 channel EEG system (Compumedics, Charlotte NC) will be used to collect neuromotor data. Data will be processed using Curry and EEGLab. Vicon Nexus system, Vicon Bonita cameras, and the Upper Limb Model set for bony landmarks will be used to capture movement patterns during novel tasks. Motion capture will allow fine motor movements to be tracked throughout the completion of the novel tasks to assess compensation or stiffness in movement. Movement patterns were assessed using motion capture data was evaluated and processed using Visual 3D. More specifically, the degree of joint angle change at the elbow was calculated for healthy controls and the RA participant. Joint angle measurements were expressed in degrees and calculated over one marble trial. The Biopac system was utilized with an attached pressurized sensor to track the return to a neutral position between marbles. This designated and marked the start and end of one marble trial for EEG assessment and motion capture data. Other laboratory supplies that will be needed include: alcohol swabs, gloves, sanitizer, and face masks.

Procedure:

In the methodology, a novel marble task that assesses the motion of the upper extremity and neural connectivity with the brain will be employed. First, participants had the nature of the

study explained in-depth through the use of the informed consent document. Their exact responsibilities as a participant were outlined including expected time commitments. The document covered that there are no benefits or risks associated with participation in the study. The participant had the opportunity to ask any questions and knew that they are free to choose to not participate at any time. The participants were then asked to sign the informed consent document after having the study orally described and having all of their questions answered. Participants first completed a short pre-participation survey free of identifiable markers. The survey included hand dominance and a few questions regarding the effects of RA on everyday activity completion. The survey used a rating system of one through five.

EEG was employed to further examine communication within the nervous system throughout the novel tasks. EEG cap data may show differences in motor planning and processing. An EEG 64 Gel Cap was utilized to track frontal cortex processing throughout the trials. To set up the cap, participants were seated in a chair, and any hair care products were removed from the hair with an alcohol-saturated cotton pad. The forehead skin was prepared by wiping the area with a cotton pad, and a solution of pumice and Vitamin E called Lemon Prep, thereby removing any residual oil and dirt from the skin. Then, the participant was fitted with a 64-channel EEG cap to record neural activity. The crown of the participant was measured and marked for proper placement a third of the way the participant's forehead for cap placement. Once the cap was in place and properly aligned, the scalp under each electrode was prepared by filling the EEG cap sponges with a mixture of a distilled ware and saline solution with a 16-gauge blunt needle. This increased connectivity and reduced impedance to the electrode. Eye movements will be recorded with electrodes placed above and below the eye. The electrodes were applied to prepped skin using Biopac conductive adhesive gel.

Motion capture techniques were also employed using the Vicon Nexus system, Vicon Bonita cameras, and the Upper Limb Model set for bony landmarks. The upper limb model was utilized to track motion throughout the trials. To set the upper limb model up, the participant was seated and asked to remove any hand or arm jewelry. Participants were given medical gloves to wear throughout data collection. After the latex gloves were put on, open finger gloves were placed on top before attaching hand markers on each for motion tracking. The participant then had a thorax marker placed in the middle of the shoulder blades using a velcro plate on a wearable strap. Four velcro sleeves were then wrapped around both upper and lower arm regions of the participant. The upper arm sleeve was wrapped around the region of the arm between the shoulder and elbow. The forearm sleeve covered the region of the arm between the elbow and wrists. The appropriate motion capture markers were placed on the sleeves. The markers included the thorax, left hand, left upper arm, left forearm, right hand, right forearm, and right upper arm (See Figure 1.1). The markers were directly attached to the sleeves by their velcro backing and not directly placed on the skin of the participants. The sleeves were used to ensure the motion capture plates stay attached throughout the completion of the novel task.

Pearl motion capture markers were utilized for the static trial only so that data can be later processed. The pearl markers were placed on the medial and lateral sides of the shoulder, elbow, and wrist joints on each arm. Two markers were also placed on the hand on the pinky and pointer fingers on the proximal interphalangeal joints (See Figure 1.1). Before attaching the markers, each area of the skin was prepped using an alcohol pad. The markers were attached to the skin using silicon adhesive gel tape. The pearl markers were then removed immediately following the static calibration.

Figure 1.1 Upper Limb Model and Pearl Markers

Participants were expected to participate in a total of eight trials of a marble novel task. Four trials were completed using bigger-sized marbles and four for the smaller set. In each trial, the participant was expected to manipulate a total of fifteen marbles. In all, the participant completed the novel task using sixty large marbles and sixty small marbles for a total of one hundred and twenty marbles manipulated. The trials were randomized so that order did not matter or influence data outcomes. The participant had the opportunity to rest between trials for about one minute. EEG and motion capture data were used to assess neuromotor processing and movement patterns. The start time for each trial was recorded so that frontal processing before and after movement can be designated. The experiment and surveys in their entirety took around two hours to complete fully.

Before the start of data collection, the RA participant completed a survey assessing RA functionality. All participants completed a static calibration trial. Static calibration was completed by the participant holding a static position for thirty seconds for recording by the Vicon Nexus motion capture system. The static calibration position required the participant to hold both arms extended at the level of the shoulders with the elbows bent at right angles and the fists closed tightly. Following the static calibration, the previously discussed pearl markers were removed so that the movement trials could be recorded.

The experiment space (shown in Figure 1.2) had an empty bowl in front of the participant's designated hand on the pressurized sensor and a bowl of the specific marbles placed in front of the participants resting hand on the opposite side of the table. Participants began each trial in a neutral start position with both palms facing downward before being instructed which hand to utilize for the designated task. At the start of the trial, the participant was instructed to pick up a set of large tweezers with the designated hand. The participant then reached across the table to pick up one marble from the filled cup with the tweezers. The participant then reached back across the table while gripping the marble in between the tweezers. Next, the participant placed the manipulated marble in the empty. The participant finished the trial by returning to the start position, before moving to pick up the next marble. This pattern of motion was completed continually until all marbles had been moved to the new cup (See Figure 1.2). If at any point the participant dropped a marble while moving the participant left it and restarted by picking up a new marble. Dropped marbles were accounted for when calculating error. At the succession of the trials, the markers and EEG cap were removed.

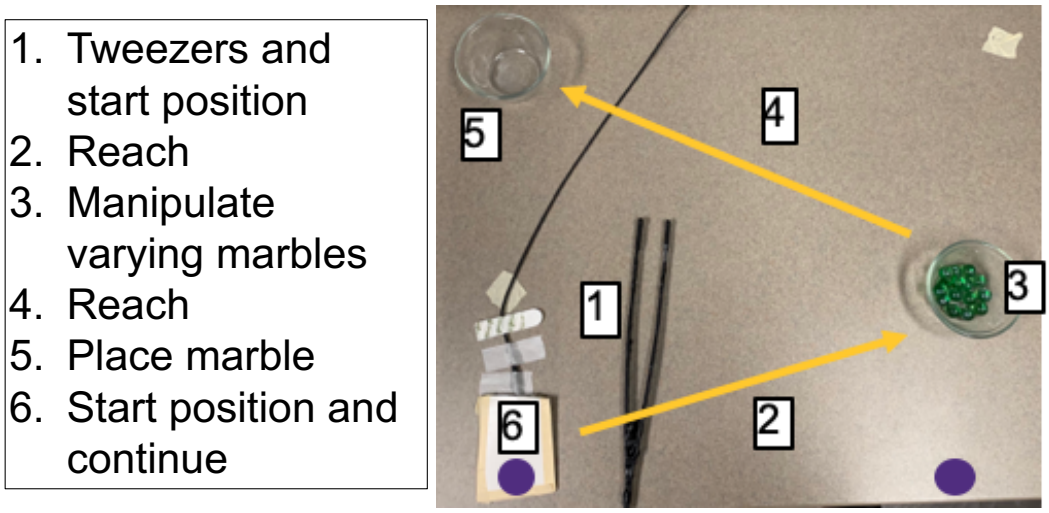


Figure 1.2 Experiment Space and Novel Marble Task
The sequence of actions taken by the participant during the procedure are shown numerically above labeled as 1 through 6. The purple circles designate the neutral start position between each marble trial. The golden arrows show participant movements across the experiment space.

RA participants were then asked to complete a short post-participation survey free of identifiable markers. The survey included a few questions to assess participants' opinions about the marble novel task. The survey used a rating system one through five and marked the completion of participation.

Results:

The protocol evaluated elbow joint angle and brain activation. Results were processed based on three categories of participants. A young healthy control, middle-aged healthy control, and rheumatoid arthritis participant all had data processed based on their trials. The results exhibited similar movement pattern trends between the young healthy and middle-aged healthy controls that were not followed by the RA participant. Young healthy and middle-aged healthy controls followed similar patterns of joint angle change at the elbow for the large marble size (See Figure 1.1). The young healthy control explored 38.3° throughout one large marble tile

while the middle-aged healthy control moved the elbow joint a total of 65.1°. The rheumatoid arthritis participant experienced a much smaller degree of change only moving the elbow joint a total of 18.6°. This trend can be seen in the curvatures displaying elbow action throughout the trial (See Figure 1.3). The curvatures of the healthy controls are very similar in slope showing a similar joint action pattern. The RA participant's joint angle pattern is significantly different as shown by the curvature of their elbow joint angle action.

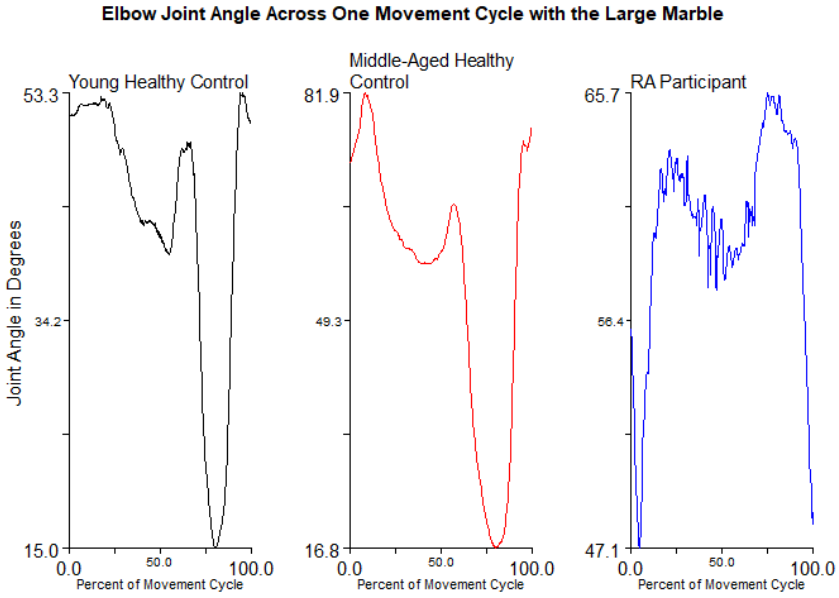


Figure 1.3 Large Marble Elbow Joint Angle

Elbow joint angle change was also processed throughout the small marble manipulation for the young healthy, middle-aged healthy, and RA participants. The similarities between the young healthy and middle-aged healthy controls were evident with the small marble size as well (See Figure 1.4). The young healthy control explored 37.6° of elbow joint angle. The middle-aged participant moved the elbow joint a total of 51.9° throughout the movement cycle. Again, the curvatures of the healthy controls are very similar in slope showing their similar joint action pattern (See Figure 1.4). The RA participant had a much lower degree of change at the elbow, moving only 14.3° during the completion of one trial. With the small marble size, the RA

participant did not explore a large area of the experiment space through elbow joint action shown through the altered pattern of joint angle curvature (See Figure 1.4). The RA participant moved the elbow joint significantly less than the healthy controls for both the small and large marble sizes but still overcame the movement problem. This indicates that compensatory movements were utilized by the RA participant in some manner to manipulate the marbles.

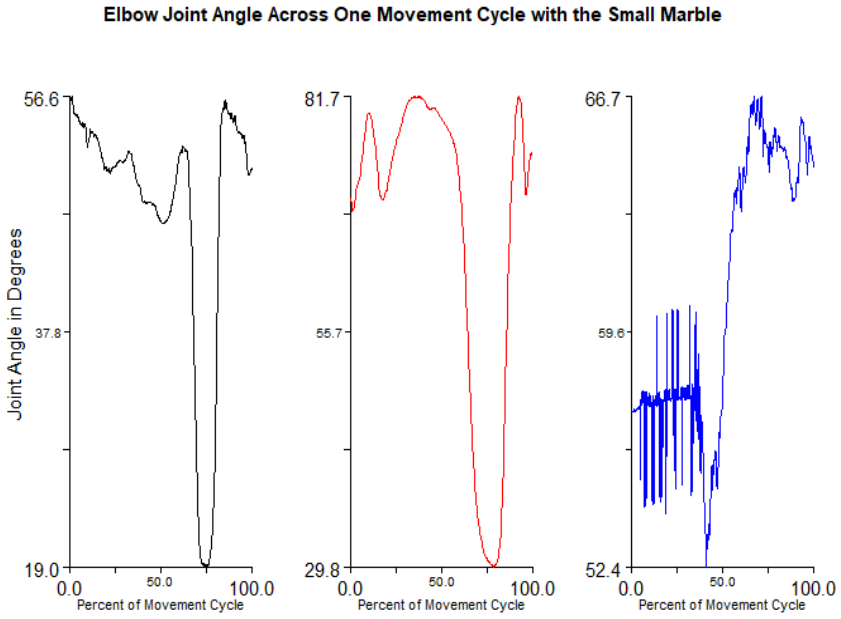
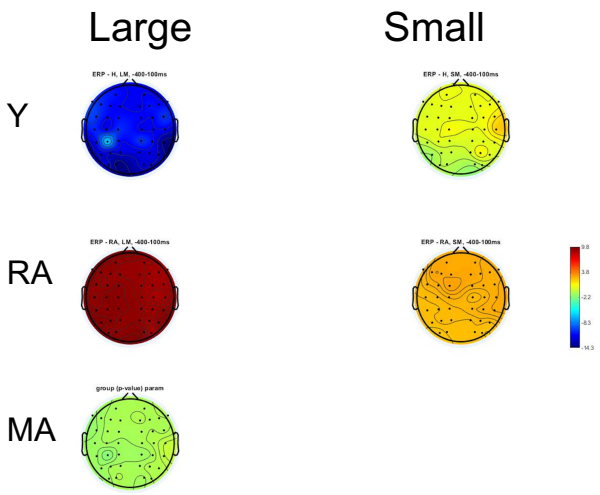


Figure 1.4 Small Marble Elbow Joint Angle

Figure 1.5 includes a series of brain activation maps showing the differing levels of arousal across participant trials. As shown, RA the young healthy control showed the lowest activation for the large and small marbles sizes. The middle-aged healthy control had brain activation for the large marble size between that of the young healthy control and the RA patient. Brain activation could not be processed for the middle-aged healthy control with the small marble size, but it is predicted that activation would follow the same trend. The RA participant's brain activation shows significantly higher brain activation for both the small and large marbles than healthy controls.



1.5 Brain Activation Maps

The RA participant performed movements with more error than healthy controls for both the small and large marble size (See Figure 1.6). Errors were accounted for when the participant dropped a marble or picked up multiple at a time. For example, The RA participant performed two errors with the large marble size while the young and middle-aged healthy controls did not. The same trend was seen with the small marble size. The RA participant performed five errors with the small marble size. The middle-aged control dropped three small marbles while the young healthy controls performed two errors.

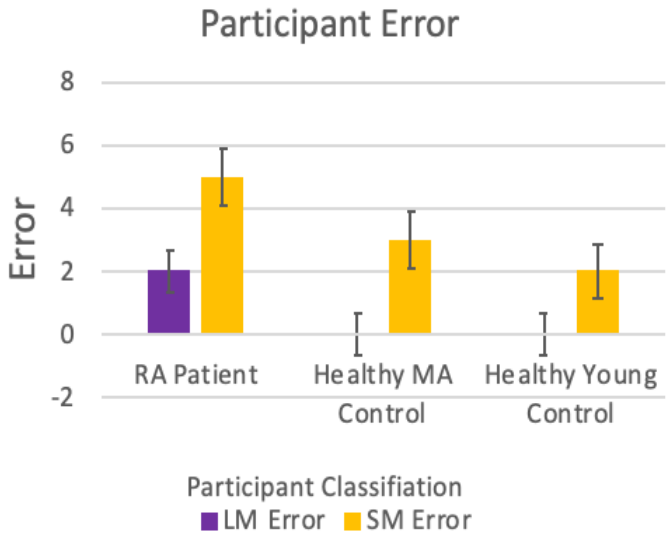


Figure 1.6 Participant Error

Discussion/Closure:

Similar to Kauranen et. al (2000), we observed motor deficits in RA patients, specifically reduced elbow joint angle action. The quantitative results showing the lowered degree of elbow joint angle change matched the qualitative compensation observed in the RA participant. The dynamics of the RA participant's movement showed clear use of compensatory actions to solve the movement problem. For example, the RA participant consistently used a twisting action at the shoulder rather than a movement of the elbow joint to manipulate marbles throughout the trials. In addition, the participant leaned the whole body at the trunk to facilitate the movement of the marbles to the empty cup. These compensatory actions were evident throughout the completion of all trials (Barbier et al. 1999) and Simonsen et al. (2019) studies. The observed compensatory actions were unconsciously adopted most likely through habituation and altered neuromotor processing in the central nervous system (Simonsen et al., 2019). Additionally, there was a continual slight degree of angle change at the initiation of movement during small marble manipulation. The combination of visual observation and Visual 3D analysis concluded the fluctuations in curvature that indicate a small degree of elbow angle change to be the participant's tremor. Other compensatory movements were observed throughout the RA participant's trials. The RA participant also utilized both hands to manipulate the marbles. The hand that usually rested in a neutral position in the healthy controls was utilized by the RA participant to angle and position the resting empty bowl so that marbles could be more effectively placed in it. The RA participant also reported subjective feelings of fatigue and lowered grip strength during the small marble manipulation trials. Grip strength in the hand depicts the overall functionality of the upper extremity and needs to be a therapeutic treatment focus (Adams et al., 2004). The subjective reports from this study’s RA participant echo the

same sentiment, as the marble task-initiated fatigue and reduced grip strength in the right hand influenced the participant to opt-out of completing the last small marble trial with the right hand. The self-reported fatigue and grip strength align with the findings of Van Zanten et al., (2015) and Erol et al. (2016) who reported higher levels of exhaustion and poorer force production when grasping in RA patients. Lastly, the RA participant constantly readjusted their handgrip on the tweezers while completing the trials to more easily manipulate the marbles. These qualitative findings need to be applied to further RA participants to assess trends among compensatory movements among the RA participants.

Further, the RA participant's increased neural activation with the large marble size may be due to more concentration, effort, and workload. The high level of brain activation indicates greater neural processing of the task within the central executive system. Surprisingly, the small marbles initiated lower amount processing. Subjective reports of fatigue and reduced grip strength coupled with the higher error may have influenced feelings of defeat and lowered motivation. As previously discussed, RA has been found to affect brain functionality, cognition, and motivation based on self-efficacy (Azeez et al., 2020; Bartolini et al., 2002; Knittle et al., 2011; Simonsen et al., 2019; Wartolowska et al., 2019). The post-participation survey of the RA participant revealed that it was difficult to manipulate the tweezers due to decreased grip strength and that it was very difficult to complete the small marble trials with the right hand. The level of difficulty was so strenuous that the participant opted out of completing the second small marble trial with the right hand. The perceived sense of low control over the task coupled with decreased performance achievement may have influenced motivational factors for the RA participant (Knittle et al., 2011). As previously discussed, RA participants are greatly influenced by motivational and subjective self-efficacy factors (Knittle et al., 2011). Feelings of defeat coupled

with fatigue and lowered grip strength may have lessened effort and workload motivation leading to lower brain activation. In future research, a more detailed analysis of neural activity and motivational influences may need to be considered.

As with any study, limitations affected the results and findings of this research. First, the pandemic and timing of the vaccinations affected the ability to recruit RA participants safely. RA participants are at high risk for COVID-19 due to the nature of the disease and age-onset typically seen. For this reason, only one vaccinated RA participant was able to complete the study. For future implications, RA participants will be reached using communication with local Vidant rheumatologists and through advertisement measures such as flyers and social media postings. Another limitation to this study is the technical difficulties experienced throughout data collection and processing. Due to the Vicon Bonita camera system glitches, several participants' motion capture data could not be processed. The cameras did not pick up all of the pearl markers in the static calibration trials making the data unable to be processed in Visual 3D. For some trials, markers appeared jumpy or several nonexistent markers were added to the Vicon Nexus motion capture trial, making the trial difficult to process and full of gaps. Additionally, the Vicon Bonita Cameras had to be continually recalibrated, focused, and reset to collect feasible trials throughout. After adjustments, the threshold and camera aperture settings were optimum by the end of data collection. Human and technological error both serve as limitations to the study findings. The hopes for the continuation of this project are that more RA participants can be evaluated to see if the current trends in results are reflected among other RA participants. The data can then be applied to future therapeutic technique development and treatments as more is understood about RA-associated motor outcomes.

The field of occupational therapy is focused on the holistic health of both the body and mind. RA affects both the physical and mental well-being of clients. Joint erosion and pain may contribute to deteriorating neuromotor control and motor capabilities. Further, clients may emotionally suffer due to the constraints of the disease and experienced debilitation. The cognitive demand for RA patients could potentially be higher, thus requiring adaptions in therapeutic settings and daily life. Fine motor capabilities in the upper extremity affect the efficiency at which RA patients can perform activities of daily living, live independently, and engage in meaningful occupations. The results of this study provide more detailed information about how RA affects motor processing and performance outcomes through compensatory movements that are directly correlated to clients' overall well-being. With RA diagnoses projected to exponentially increase in the coming years, more research is needed to understand how RA affects motor capabilities and neural communication. With more knowledge on this crippling disease, better therapeutic techniques could potentially be developed to combat the declining functionality due to RA.

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