Challenging the limits of the motor system: Differential kinematic and electromyographic outcomes associated with age

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Abstract

The measurement and assessment of maximal voluntary rate (MVR) are essential to our understanding of the limiting factors associated with motor control of human movement. However, very little is known about the dynamic changes that occur throughout an MVR task and how these changes impact upon normal functional capacity, especially with respect to aging and selected clinical populations. The purpose of this study is to test the functional capacity of the motor system and to compare any age-related changes in kinematics and electromyographic (EMG) parameters between young and older groups. Using a simple but novel MVR task (e.g., flexion and extension of the index finger for 20 s) developed by Rodrigues and colleagues (2009), we collected data on both the dominant (right) and non-dominant index fingers. With respect to the dominant finger, both groups experienced an immediate and continuous decline in peak movement frequency and velocity of the flexor and extensor. Significant group differences were observed in amplitude and peak velocity of flexor and extensor. There was a significant group x time interaction with the older group demonstrating a progressive increase in muscle activation pattern (e.g., co-contraction) over time while the younger group maintained their initial levels relatively constant. There was an interaction with peak velocity of the extensor muscle whereby the young decreased at a faster rate than the older group. With respect to the non-dominant index finger, the median frequency of the extensor was different between groups with the young experiencing a leftward shift indicative of fatigue. The young group declined in maximal velocity of the extensor as well as the pre-post difference in maximal voluntary contraction of the extensor. Although the young group exhibited signs of peripheral fatigue on the non-dominant side only, there were no signs of peripheral fatigue on either side of the older group. We conclude that the chosen MVR task challenges the central limits of the motor system differently with age, not only in the way that the two groups respond in terms of movement kinematics and patterns of muscle activation but also in the way that elderly appear to pre-program their maximal voluntary movements. We also conclude that hand dominance plays a differential role in the outcome of the MVR task in that the non-dominant side adjusts differently to the MVR in terms of peak velocity and median frequency (extensors) and that the young appear to experience a peripheral form of fatigue that is not seen in the elderly.

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Table of Contents

LIST OF FIGURES

> "In physiology, as in all other sciences, no discovery is useless, no curiosity misplaced or too ambitious, and we may be certain that every advance achieved in the quest of pure knowledge will sooner or later play its part in the service of man".
>
> Ernest Henry Starling

Introduction

"I think the 21st century will be the century of complexity. We have already discovered the basic laws that govern matter and understand all the normal situations. We don't know how the laws fit together, and what happens under extreme conditions. But I expect we will find a complete unified theory sometime this century. There is no limit to the complexity that we can build using those basic laws".

Stephen W. Hawking (2000), theoretical physicist

Challenging the limits of the motor system is a very effective way to explore its functional capabilities and to predict its behaviour under normal and pathological situations. To this end, an extensive array of work has been done using static and dynamic models of force production, to measure both at the level of cell biochemistry and electrophysiology. The function of the motor system has been described in situations of maximal force production by the electromyographic methods in order to describe the muscle activation, nerve conduction velocity, and spectral frequency analysis of the signal. Lately, with the advent of "cutting edge" and sophisticated imaging techniques and methodologies, we have been able to visualize the regional brain activation where the signalling of muscle force production is initiated. All the discoveries made thus far have allowed us to better understand and appreciate the complexity and functionality of the motor system; however, it is surprising that the variables of interest used to date have been predominantly associated with the variety of factors that influence force production. Aside from the determination of submaximal or maximal force, the kinematic parameters consisting of maximum frequency and velocity represent an alternative and essential way of assessing the limits of a different dynamic aspect of the motor system. For example, the determination of the maximal voluntary rate (MVR) of index finger contraction serves as a model that can be easily attainable by the majority of the population. Being able to describe and to better understand the behaviour of the motor system during an MVR task is highly desirable and will assist us in determining the limits of movement that involve muscle pattern activation and kinematics. Despite this, it is remarkable that very little is known about the behaviour of motor system in terms of its maximal voluntary movement rate either from a kinematic (e.g., frequency, amplitude, velocity) or electromyographical (e.g., skeletal muscle co-activation or coordination) perspective. Thus, our discussion will focus on a very simplistic yet fascinatingly complex processing movement involving flexion and extension of the index finger at maximum voluntary speed. There is a tremendous volume of literature in psychology describing finger tapping at various speeds and modes; which is quite different from the MVR task described previously. Furthermore, the type of data extracted from these studies in psychology is not totally relevant to the interests of physiologists who are interested in not only assessing neuromuscular performance but also the factors associated with the frequency and velocity of movement. A physiologist would typically describe the MVR phenomenon as an ascending order model beginning with the basic kinesiological characteristics of the activity and then moving proximally along the motor system from the muscles, peripheral nerves, motor neurons and eventually terminating at the supraspinal level. Our initial interest in the MVR design is to explore the contributions and adaptations of the central nervous system in fatiguing exercises or activities that do not require the maximal force generating capacity, thus minimizing the influence or presence of peripheral fatigue. The corticomotor system can include limitations that include executive de-motivation until physical fatigue and pain. However, the effective exploration of any problem needs to proceed in a two dimensional model fashion; both vertically to the depth of the problem "zooming" in for the details and laterally to its full horizons in order to capture the entire scope of the phenomenon at different conditions and populations. We see the "lateral" dimensional analysis of the MVR model as the primary outcome for this thesis. Later, we will identify an obvious knowledge "gap" in the literature when applying the MVR model to populations of different ages. Taking into account the significant changes that occur in the human motor system with age, this work will be a significant contribution to the body of knowledge that presents a relatively novel way of exploring the motor system. We will apply and compare the index finger MVR model in young (20-30 years) and older (≥ 60 years old) groups using the index finger of the dominant (right) and non-dominant hands. Once we have a better grasp of the normal kinematic and electromyographic responses of different age groups to the demands of this model, we will be able to apply it as an assessment tool to different clinical populations presenting with known or suspected motor system deficits such as Parkinson's disease or stroke.

Maximal voluntary rate model:

Rodrigues and colleagues (2009) initially used the MVR model in healthy young and middle-aged individuals. The MVR task was performed using the index finger in a flexion/extension mode for 20 seconds. Each subject was directed to perform the task at maximal speed (velocity) while maintaining the rate (frequency) constant. The main finding of this study was the failure to sustain the required maximal rate for more than a few seconds into the task due to the breakdown in central motor control. This conclusion was based upon the fact that the measures of peripheral fatigue such as maximal voluntary contraction of the finger flexor and extensor did not change from pre- to post-task. In other words, the MVC capacity was preserved directly following the task as well as selective fatigue of the fast twitch fibres which was assessed indirectly by measurement of the pre-post maximal velocity). Finally, the pattern of muscle activation was observed to shift from a tri-phasic to a co-contraction pattern early in the task signifying the breakdown in the motor control. Therefore, it has been demonstrated by this group that the failure to sustain the MVR task was central in origin and can be applicable to specific clinical populations (e.g., Parkinson's, stroke patients) where the inherent nature of the disease or condition would allow us to explore the functional limits.

In order to separate the central fatigue from the central adaptations (response to peripheral fatigue) that could potentially be caused by the peripheral fatigue, the task has to be peripheral fatigue free. The MVR task comprising of a 20 second flexion / extension index finger movement proposed by Rodrigues and colleagues served the purpose and was demonstrated to preserve the force generating capacity immediately following the completion of the task. However, the follow up studies from the same laboratory group used an abbreviated time task, thus reducing the time from 20 to 10 s since central failure was observed within the first 5 s of the MVR task (Teo, Rodrigues, Mastaglia & Thickbroom, 2012a; Teo, Rodrigues, Mastaglia & Thickbroom, 2012b; Teo, Rodrigues, Mastaglia & Thickbroom, 2012c).

Cortical processing of MVR tasks

It has been previously demonstrated that any demanding physical task is associated with an increase in corticomotor excitability during exercise, followed by a transient post-exercise facilitation (Samii et al. 1996; Lentz & Nielsen 2002) and then an extended period of depressed excitability (Sacco, Thickbroom, Byrnes & Mastaglia, 2000; Taylor, Butler & Gandevia, 2000), as well as alterations in both short- and long-interval cortical inhibition (Benwell, Mastaglia & Thickbroom, 2006). Using the index finger paradigm, Teo et al. (2012c) studied the transcranial magnetic stimulation (TMS)-induced changes following the performance of demanding repetitive tasks and observed that the corticomotor excitability initially increased and then declined after 2 min followed by a continuous decrease in excitability that was maintained for up to 6 min. Interestingly, when using a less demanding non-fatiguing task at a lower sustainable rate, there was an even stronger post-exercise depression. A similar decrease in excitability occurred following the maximal voluntary contraction (MVC) task (Thickbroom et al. 1999); however, the significant feature differing the MVR task from MVC is the absence of the peripheral fatigue that could potentially be contributing to this decreased post-exercise excitability. The authors suggest that this hypoexcitability associated with both MVR and MVC tasks may indicate that it is the demanding nature of the tasks (MVR and MVC) rather than the task itself that causes the changes in the corticomotor system. The changes in response to the TMS stimuli between the index finger flexion / extension task performed at MVR and at a slower rate suggest the difference in neuronal processing between the two tasks. The reduced corticomotor excitability following this rate-demanding task may be an indicator of central motor adaptation changes. Therefore, it is concluded that there is specificity to the processing of the MVR task, and it is related more to the task demands rather than to the biomechanics of the movement. Therefore, the reasons for the fast decline of the rate in MVR should be related to that central mechanism defining the movement. The interesting aspect of the post-exercise depression following the repetitive task is also the duration of this phenomenon that was greater in a less demanding task. In other words, the post-exercise depression following the sustainable rate was greater than that following half the sustainable rate task (Teo et al., 2012c). The hypothesis proposed by the author suggests that there might be a difference in motor planning of the task. This is somewhat analogous to the MVC task where the corticomotor depression following the task is interrupted if a new MVC is performed (Sacco et al. 2000). They suggested that the slower movement is planned in a closed loop design with a greater emphasis on afferent feedback sensitivity as compared to an MVR task that is conceptualized and pre-programmed before the beginning of the movement (Seidler, Noll & Thiers, 2004; Wagner & Smith, 2008; Shadmehr, Smith & Krakauer, 2010). Differences in neuronal processing of the MVR task have also been observed between the dominant and non-dominant hemispheres. It appears that the most demanding task (MVR on the non-dominant hand) was associated with the least changes in post-exercise depression and the greatest change was observed on the least demanding task (submaximal rate, dominant hand) (Teo et al., 2012c).

A comparative study of TMS responses following a fatiguing and non-fatiguing muscle contraction shed some additional light on the processing of the MVR task. Motor evoked potential (MEP) decrements were observed in the dominant hand in the tapping of index finger and thumb, and not observed in the non-dominant side, while no change was observed following the sustained grip on either hand. The changes in MEP in this case were not associated with general fatigue or hand fatigue. Therefore, the reports from this group support the point of view now present in the literature stating that repeated central initiation of movement is associated with the depression of MEP even in the absence of fatigue and are of central origin by their nature. (Kluger, Palmer, Shattuck & Triggs, 2012)

The final argument in the discussion for the central origin of the rate failure (frequency) on the MVR task is the improvement of performance observed following the central intervention. If the improvement in the task can be observed as a result of "plasticity related learning", then the mechanism of the initial failure can be attributed to the central parameters. The two learning modalities explored for this purpose were elementary motor learning and neuro-modulation using ITMS (Teo et al., 2012a). A significant improvement in both initial rate and the rate of decline was observed after the fifth and sixth trials following the "sham" intervention as a result of short-term training and from the first trial on following TMS. From the described findings, it is suggested that the mechanism initially causing the rate of the MVR to decrease so quickly is the breakdown of motor control at the central level.

The neurological nature of dynamic contractions has been demonstrated to be very different from the static contraction as seen from the functional magnetic resonance imaging (fMRI) studies (Karni, Meyer, Jezzard, Adams, Turner, & Ungerleider, (1995); Thickbroom et al., 1999). For instance, the fMRI from the sensorimotor cortex obtained at the isometric finger flexion rate of 5 and 10 % MVC were compared to images during dynamic finger flexion at 1, 2 and 3 Hz of the same intensity. The signal was stronger for the dynamic task even when compared to the static task of a stronger intensity. The signal at the dynamic task did not vary significantly with the change of the motion rate while the response was negligible in most static tasks. In fact, the fMRI signal obtained at 1 Hz and 5% MVC was comparable to the static task signal at 50% MVC obtained at the previous trial of this research group. Therefore, the pattern of cortical activation in dynamic contraction is different than that of a static isometric task (Thickbroom et al., 1999).

The repetitive ballistic finger movement involves both motor sequence and control of graded force. The areas of the cortex responsible for these parameters are the rostral supplementary motor area (SMA) (Luders, 1996) and primary motor area (Maier, Bennett, Hepp-Reymond & Lemon, 1993) respectively. Therefore, the ballistic movement might require greater activation from the cortex, incorporating primary and supplementary motor area. This high cortical demand might be the reason for the fast central failure of the dynamic task observed by Rodrigues et al. (2009). The investigation of fast rate movement of the fingers (1-2-3-4) of the dominant hand to the thumb of the same hand has in fact revealed a strong contribution of SMA, with no involvement of primary sensorimotor cortex. It is interesting that caudal SMA was activated more than rostral when the initiation of the movement was unpredictable. The involvement of the caudal SMA was therefore linked to the execution of externally cued movements (Thickbroom et al., 2000).

Summary of the MVR findings

To summarize the findings of the MVR studies, it appears that the fast repetitive movement of index finger (MVR task) in young healthy population is characterised by a rapid slowing of the movement rate without any signs of peripheral fatigue. We can also trace the central changes by observing the increase in post exercise depression, short interval cortical inhibition and a decrease in motor cortex excitability following the described task. The improvement seen following the short interval training and enhanced by TMS with the preservation of the maximal rate leaves us confident about the central nature of fatigue leading to the fast failure of the task.

In order to have a better understanding of the possibilities where central failure can occur, we will briefly describe the current views on central fatigue present in the modern literature.

Central fatigue

Definition and methods of detection

A progressive task-induced reduction in voluntary activation or neural drive to the muscle is referred to as central fatigue (Taylor, Todd & Gandevia, 2006). Another definition proposed by Di Lazzaro et al. (2003) for central fatigue (or cortico-spinal fatigue) is an adaptation in the motor cortex or spinal cord following a period of prolonged effort which leads to lack of the ability of voluntary command to recruit spinal motor-neurons fully, in fully motivated subjects.

The suboptimal central activation causes the so-called "central activation failure". The increase of this parameter is an indicator of the central fatigue (Zwarts, Bleijenberg & van Engelen, 2008). The appearance of central fatigue is revealed through impaired force generation (Taylor et al. 2006). The presence of this phenomenon is determined by a superimposed supra-maximal twitch (twitch interpolation) that momentarily increases force while performing a maximal voluntary contraction. This additional force produced by the muscle indicates that muscle activation was impaired proximally to the neuromuscular junction (Gandevia, Allen & McKenzie, 1995; Crenshaw, Karlsson, Gerdle & Friden, 1997; Taylor et al., 2006).

In order to confirm the presence of central fatigue, the twitch interpolation technique is usually used (Gandevia, 1996). This technique allows us to analyze the central activation failure by applying electrical stimulations to the motor nerve and motor endplate while the participant is performing the maximal voluntary contraction task. If the activation of the cortex is optimal, no additional force should be created. However, the suboptimal cortex stimulation will reveal itself with an additional force production indicating the presence of central activation failure. This technique allows us to analyze the central activation failure over time; however, it is unable to determine whether the origins of central activation failure are spinal and cortical in nature (Zwarts et al., 1996).

In order to quantify the spinal component of the central fatigue, the mean spectral frequency of EMG must be analyzed. The impaired alpha motor neuron firing causes the amplitude of EMG signal to be reduced at task failure. This failure may be a result of either loss of recruitment or indicate that a few synergistic muscles got activated at the same time (Miller, Kent-Braun, Sharma & Weiner, 1995; Gandevia et al., 1995; Taylor & Gandevia, 2008).

By stimulating the motor cortex by TMS, we are able to explore the origins of fatigue in the higher nervous system sites (Di Lazzaro et al., 2003; Gandevia, 1998; Taylor et al., 2000). Supraspinal fatigue is a component of central fatigue and is defined as the loss of force caused by suboptimal output from the motor cortex (Taylor et al. 2008). A greater interpolated twitch force, increased muscle excitatory potential and prolonged silent period/latency (firing of inhibitory neurons) from TMS indicate the presence of supraspinal fatigue, particularly towards the end of an MVC when the interpolated twitch can be recorded as high as 50-100% (Gandevia, 1998).

When the muscle is maintained ischemic by supramaximal inflation of the blood pressure cuff following a fatiguing contraction, the relationship between supraspinal, spinal, and peripheral fatigue can be made. The metabolic environment of the muscle is maintained in the fatigued state and the continuous firing of III and IV sensory afferent are preserving the fatigue state. During this time period, the muscle excitatory potential and silent period on the EMG following TMS stimulation appears to be recovered. Therefore, the input from III and IV muscle sensory afferents inhibit the depolarization of cell bodies of the spinal alpha motoneuron as opposed to neurons in the cerebral cortex (Gandevia, 1998).

Causes of central fatigue

Central fatigue may arise at the cortical and spinal levels or as a result of a feedback from the muscular sites. The following are mentioned as potential causes of central fatigue:

- Decreased sensitivity of alpha motoneurons
- Loss of recruitment of high threshold motor units
- Increased negative feedback from muscle afferent types III and IV sensory neurons
- Loss of positive feedback from muscle spindle type I sensory afferents
- Central conduction block from demyelination or motor neuron dropout
- Reduced central drive from increased inhibitory interneuron input to motor cortex (Dobkin, 2008)

The first four origins named above are spinal in nature. Motoneuron discharges can be reduced by peripheral reflexes as a response to the metabolic changes in a fatigued muscle (Bigland-Ritchie, Dawson, Johansson & Lippold, 1986). These metaboreceptors (group III and IV afferents) appear to be stimulated by ischemia, hypoxemia (Arbogast et al., 2000) and extracellular accumulation of potassium and lactate (Rotto & Kaufman, 1988; Darques, Decherchi & Jammes, 1998). Therefore, stimulation of these metaboreceptors may inhibit the activity of the alpha motoneurons (Duchateau & Hainaut, 1993; Garland & McComas, 1990; Kaufman, Rybicki, Waldrop & Ordway, 1984; Martin, Smith, Butler, Gandevia & Taylor, 2006).

The motor neuron can also adjust its discharge rate through the changes in its membrane intrinsic properties according to the constant excitation coming from III and IV afferents (Windhorst, Kirmayer, Soibelman, Misri & Rose, 1997; Gardiner, 2001).

The limitation of alpha motoneuronal activity has also been associated with the muscle spindle activity (group Ia and II afferents) that provides feedback to the CNS with information concerning muscle length and the change of length (Gandevia, 1998; Bongiovanni & Hagbarth, 1990).

The discharge rate of these afferents signals decreases progressively during a sustained contraction below 30% MVC (Macefield, Hagbarth, Gotman, Gandevia & Burke, 1991). Finally, motoneurons can be inhibited by Renshaw cells, by the descending drive or peripheral feedback (Hultborn, Lipski, mackle & Wigstrom, 1988). The Renshaw inhibition has been shown to be maximal at the maximal efforts and then to decrease during the contractions of 20% MVC.

There are two main hypotheses for the origin of the supraspinal fatigue (Taylor et al., 2006). These include the following:

- Mechanisms that make the descending output from motor cortex less in amplitude (properties of corticospinal neurons or input to them)

- Mechanisms that make the descending output from motor cortex less efficient (motoneurons are less responsive to descending input)

Complementary to the mechanisms above are the altered neurotransmitter and chemical reactions within the cortex. Increased brain serotoninergic activity limits central command and motor unit activity following fatigue. Levels of serotonin are regulated by a rather complex interaction of tryptophan and branched-chained amino acids. In addition, catecholamines (e.g., epinephrine, norepinephrine, and dopamine) may have an affect on fatigue by influencing motivation and motor action. Glutamate, acetylcholine, adenosine, and gamma-aminobutyric acid are suggested to be involved in the development of central fatigue. End products of chemical reactions as well as endogenous substrate supply may contribute to the impaired central functioning. For example, the accumulation of ammonium ions leads to drop in motor cortex activity and brain glycogen depletion may significantly decrease cerebral functioning (Taylor et al., 2006).

Central and peripheral age-associated changes of the motor system

We will now begin to examine the evidence associated with age-related changes to the motor system. The simplest phrase to summarise the changes that take place in the motor system with age would be the following: they decline. Researchers have been investigating different aspects of this issue; however, the results from a multitude of studies would still reach a similar output. Since the motor system is traditionally divided into peripheral and central parts, we will suggest a retrograde review of changes that take place in the motor system with age. We will start with the musculoskeletal architecture and progress to the supraspinal centers.

Changes in the skeletal muscle architecture have been known to occur with aging. Sarcopenia or loss of muscle tissue is a common condition in aging. The most common reasons responsible for this condition are the loss of muscle fibres and the reduction of the size of the muscle fibres (Lexell, Taylor & Sjostrom, 1988). The muscle fibre can be lost either following some permanent irreversible damage (Anianson, Hedberg, Henning & Grimby, 1986; Lexell, Downham, Sjostrom, 1983) or the denervation (Lexell, Downham & Sjostrom, 1987). It appears that muscle denervation and reinnervation is a very common phenomenon in an aging muscle as it has a very similar appearance to the process present in neuropathies when similar muscle fibre types group together (Lexell & Downham, 1991). The literature supports the view that it is the lack of innervation following the degenerative changes of the nervous system that causes the loss of muscle tissue in the elderly.

The reason for the denervation is the number of functioning motor units (Doherty & Vandervoort, 1993) and motor neurons (Kawamura, Okazaki, O'Brien & Dych, 1977a) that declines dramatically with age, with the drop rate of 25 to 50% after the age of 60. The number and the diameter of the motor neuron axons are also undergoing significant changes. The loss of myelinated fibres in the ventral root between young and older adults was demonstrated to be 5% (Kawamura, O'Brien, Okazaki & Dyck, 1977b, Mittal & Logmani, 1987). It is this decline in motor neurons that causes reinnervation and as a result expansion of innervating territory of surviving neurons (Doherty & Vandervoort, 1993; Roos, Rice & Vandervoort, 1997).

The neuromuscular junction undergoes significant changes with aging as well. The majority of the literature on this subject originates from animal research with some evidence from human studies as well. The appearance of the motor end plate and the number of pre-synaptic connections has been demonstrated to vary between the age groups in human subjects. In previous reports, there has been evidence demonstrating the increase in the number of pre-terminal axon connections, the size of motor end plate (Oda, 1984), the size and the degree of branching of the postsynaptic membrane of end plate (Wokke et al., 1990). All these changes have been interpreted as compensatory mechanisms adopted by the aging motor system in order to sustain the required level of performance. The animal research on this subject reveals age-related differences in nerve ending confirming the previously discussed theory of denervation (Fujisawa, 1976, Gutmann & Hanzlikova, 1973). However, the morphological changes in motor end plate (increase in size, increased number of nerve terminals and synaptic vesicles (Prakash &

Sieck, 1998, Smith & Rosenheimer, 1982) are thought to be caused by the changes at the motor unit level. A 30-40% reduction in the number of motor units is observed as a result of reduced number of muscle fibres and increased innervation ratio in older rats. It is also interesting to note that the majority of lost motor units were fast twitch (Einsiedel & Luff, 1992 a, b). The loss of motor terminal branches at the motor end plate has also been documented.as a potentially compensatory mechanism. In addition, sprouting and the addition of the neuromuscular junction have been observed in aging rats (Balice-Gordon, 1997). Schwann cells experience the effect of aging as well. The number of cells has been reported to decrease, the nodes of Ranvier increase in size (Ceballos, Cuadras, Verdu & Navarro, 1999) and major myelin protein is under-expressed in the aging animals (Rangaraju et al., 2009).

Oxidative stress resulting from the excess of oxidative products and the lack of antioxidant activity is one of the factors associated with aging. Genetically modified rats with blocked antioxidant activity developed the neuromuscular junction changes similar to the ones present in the normally aging rats. The signs therefore associated with the age-related antioxidant effects on the neuromuscular junction were extensive sprouting and axon terminal reduction in size (Jang et al., 2010).

There has been a great deal of discussion surrounding the cerebral changes accompanying the aging process. Apart from the details of specific brain area activating during motor task, the main question is whether the adapted changes observed are resulting from degenerative alterations, compensatory mechanisms, or both by older persons due to greater acquisition of motor experience throughout the lifespan (Ward, 2006).

Over-activation of additional brain areas recruited for successful execution of a task serves as convincing evidence for the compensatory mechanisms in the elderly (Heuninckx, Wenderoth, Debaere, Peeters & Swinnen, 2005; Mattay et al., 2002). The execution of motor tasks either individually or in sequence (hand and foot flexion/extension) at a rate adjusted to the age group (1 Hz and 1.5 Hz) revealed similar kinematic results in terms of amplitude of movement and average phase error. However, the older group demonstrated additional activation of sensory processing and cerebral integration areas (e.g., insula cortex, frontal operculum, superior temporal gyrus, supramarginal gyrus, secondary somatosensory area). The increase of movement difficulty brought about the additional activation in rostral supplementary motor area, premotor, cingulate and prefrontal cortices. In the study of Mattay et al. (2002), the participants were performing a reaction time task involving finger pressing. The older group appeared to have a greater reaction time, and the performance of this task with a simple motor component was observed to activate additional cerebral areas in older group as well (e.g., bilateral primary motor cortices, supplementary motor area premotor and parietal cortices and cerebellum). The authors also report a negative correlation between the reaction time and extent of cerebral activation in the older group, arguing that this over-activation is the result of a functional cerebral reorganization essential for successful task performance (Mattay et al., 2002).

The difference in motor task learning has been demonstrated to be present in older population. When comparing the cortical activation during the motor sequence task pre and post learning among the young and older participants, it appears that the training-associated reduction in the active cortical region was significantly less in the older group. That is, the regions that were active while performing the novice task kept firing even after successful learning of the task in the older participants; whereas the younger group demonstrated a significant reduction in the active brain areas post-learning. The areas that did not reduce their activation post-learning in the older group were the bilateral pre-motor and parietal cortices, bilateral cerebellum, precuneus, left prefrontal cortex, rostral supplementary motor area, anterior cingulate motor area, caudate nucleus and thalamus (Wu & Hallett, 2005).

In his review on the compensatory mechanisms of the motor system, Ward (2006) concluded that older subjects have a very limited capacity for modifications in their primary motor cortex, and the additional activation of extended cortical regions is recruited as a compensatory technique to maintain performance at the desired level.

Separation between the peripheral and central contributors to the motor system declines with age. The entire nervous system is working as one unit and peripheral modifications have immediate responses from the center. Therefore, it is very informative to assess the performance of the aging system when examining both central and peripheral components together in their interaction. Chan, Raja, Strohschein & Lechelt (2000) studied the central and peripheral components contributing to the decline in force of the thenar muscles in older and younger populations. They used the standard twitch interpolation (Gandevia, 1996) on the median nerve and TMS stimulation of the left motor cortex pre and post fatigue procedure that consisted of 90 seconds of MVC of the thumb. As a result, the greater fatigue resistance was demonstrated in the older group with a 29% decline in MVC as opposed to a 47% drop in the younger group. This increased level of peripheral fatigue resistance was measured by a 22% decline in tetanic tension in older group as opposed to the 47% in young group while no significant difference in MEP was reported. The authors also observed significantly smaller increases in interpolation in the younger group indicating a smaller magnitude of central fatigue. They indicate the cortico-motorneuronal origin of central failure observed based on the increasing cortically evoked twitch tension. Therefore, the authors concluded that the age-related changes that caused the increase in fatigue resistance to the sustained MVC task in older group were at or more distal to the excitation-contraction coupling mechanism. It is possible that the increased number of type I muscle fibres in the older group could be one of the potential explanations for the observed changes.

Applications of the MVR model to aging

Very few studies have applied the maximal rate index finger movement model for assessing the motor function in normal, clinical, and aging population (Rodrigues et al., 2009; Teo et al. 2012 a, b, and c). However, even the very few existing publications cannot satisfy our curiosity about the details of the movement kinetics and muscle activation patterns. For example, we will mention a few findings reported recently to give you an appreciation of the actual gap in the literature in relation to the kinematical understanding of age-related differences on the MVR task.

Age, sex, and dominant side-related differences were investigated by a Spanish research team using a selection of tasks that could be potentially used for the evaluation of elderly subjects and clinical population (Jimenez et al., 2011). One of the tasks investigated was finger tapping of the forefinger and thumb at a maximal velocity for 20 times. As previously mentioned, the only parameter reported by the research team is the rate over the task. The participants were divided into subgroups according to their sex and age (41-75+ years). The authors report significant age (younger performed better than older) and sex (males performed significantly better than females) influence on performance, with no rate differences observed between the dominant (right) and non-dominant sides. The data presented in the study allows us to only estimate the actual values for rate of finger tapping for each group. However, from what we can see, the task was not performed as fast as we have previously seen in the literature, even the youngest group having a maximal rate of approximately 4.4 Hz (males) and 3.3 Hz (females). The oldest group (75+) for both females and males was reported to have a rate of approximately 3.3 Hz. It should be noted that the data presented in this study is an average of the entire trial reported as a single number per an age group (number of seconds to perform 20 taps of forefinger and thumb). Therefore, not only are we unable to judge the performance by amplitude or muscle activation parameters, we cannot follow the rate over time. It is worth noting that in the index finger tapping literature where rate is the only parameter assessed, the general trend seen is the reduction of rate with the advancing age (Ruff & Parker, 1993, Cousins, Corrow, Finn & Salamone, 1997, Nutt, Lea, Van Houten, Schuff & Sexton, 2000, Ruiz, Bernardos, Bartolome & Torres, 2007).

Another interesting study published this year from another Spanish group evaluated the validity of two tests for their applicability for the Parkinson's population (Arias, Robles-Garcia, Espinosa, Corral & Cudeiro, 2012). As a part of their evaluation, they compared the performance of young, healthy older participants, and Parkinson's patients with two finger tapping tests: FAST (maximal or as fast as possible) and COMFORT (tapping at a sustainable rate). The researchers measured the time of index finger contact with the sensor and the inter-contact time. Frequency and coefficient of variability were assessed from the inter-touch interval timings. The fatigue was assessed using TMS and was defined as a significant decrease in MEP amplitude between the pre-tapping, immediately post tapping, and the 2-minute post tapping recordings. However, the focus of the question was not the rate decline, but the inter-tap variability. It was the inter-tap variability that the authors were proposing for the clinical detection of Parkinson's disease. The interesting observation however was the presence of corticospinal fatigue registered in the young group only. The result of this fatigue was a rapid and significant drop in rate of the FAST tapping. The authors report that young participants were tapping at a faster rate from the beginning of a task when compared to the older group. But the fact that the drop in rate was observed in young group only in response to corticospinal fatigue, given that healthy older group was working at their maximal voluntary rate is of high interest to us. The authors also report the MEP facilitation observed following the completion of the task that was not followed by the depression MEP amplitude therefore they exclude fatigue of M1 or spinal motorneurons as potential “causes” of the rate decline. Again, no data on amplitude or muscle activation was reported even though EMG was recorded.

Research question and hypothesis:

Having carefully analysed the existing body of knowledge in regards to the MVR model and its applicability, we have demonstrated a clear and obvious gap in the literature regarding the application of the model to a variety of populations including healthy aging to different clinical states (e.g., Parkinson’s disease and cancer) and conditions (e.g., stroke). Since the model is aimed to reveal the central alterations, it is essential to determine and to establish how the normal aging population performs during an MVR task. In order to address this issue, we have formulated the following research question and hypothesis.

Question: How does a normal aging population perform during a brief (20-s bout) maximal voluntary rate task using both the dominant and non-dominant index finger? Our research goal is to describe how the kinematics and electromyographic parameters differ between a young and older group.

Hypothesis: Since the failure of the MVR task has been demonstrated to be centrally induced and the majority of age-related changes in the motor system are of the spinal and supraspinal origin, it is reasonable to suggest that MVR model should be capable of detecting age-related central alterations that are occurring in the aging population. When the MVR task is performed on the dominant side, we expect the older adults to perform significantly different from that of the young group in terms of a decline in mean frequency and peak velocity of flexor/extensor muscles as well as the increase in the level of co-contraction between the agonist and antagonist muscle groups.

Activation of additional brain areas has been shown to be a typical and effective compensatory adaptation frequently found in older individuals (Wu & Hallett, 2005). When exposed to a new task, both young and older subjects demonstrate additional brain activation. However, successful learning of the task was associated with reduced brain activation centers in the young and similar to pre-learning increases in activation in the older subjects. As an extension of this finding, it is reasonable to assume that older subjects are habituated to the additional brain activation and use this phenomenon to successfully accomplish both new and learned tasks. However, the young subjects do not perceive the additional brain activation as a facilitating technique. On the contrary, this energy-consuming method is only adopted in the learning of a new task. So, when the MVR model is applied on the non-dominant side, both groups perceive the task as new. Therefore, both groups will most likely take some time to learn this new movement and therefore will be demonstrating the additional brain area activation. The only difference here is that for the older subjects, additional brain activation is a common everyday phenomenon whereas, for the young group, such a method might be more challenging and fatiguing. Therefore, with this new task, the older group is quite likely to be in a more advantageous position. Consequently, the difference between the groups should not be as striking and as clear as on the dominant side.

The MVR task on the dominant side does not present a new stimulus to any group as fast repetitive movement of the dominant hand is common task in today's society life. The younger group however might be more exposed and therefore more trained for this specific task due to their day-to-day exposure to the cutting-edge technology that is being operated with the index finger motion. The only criterion that would differ between groups now would be the central age-related alterations present in the older group. Therefore, we should be able to observe a more obvious decline in the motor system performance of the dominant hand of the older group. The fact that the younger population might be more trained for index finger movement might further contribute to the difference with the older group performance, and this would increase the between-groups difference to an even greater extent.

Methods

Participants

Participants included 10 young adults (2 females and 8 males) and 10 older adults (2 females and 8 males) recruited from Concordia University and the Montreal community. All procedures were approved by the Human Research Ethics Committee of Concordia University. Upon arrival to the lab, each participant had anthropometric data (height and weight) taken and completed a general health assessment questionnaire and the Edinburgh Handedness Inventory (Oldfield, 1971). The participants were considered eligible for the study if they scored higher than the cut-off score of 40 on the Edinburgh Handedness Inventory (right handed). Exclusion criteria included any condition that might impair concentration or fine motor performance such as injuries to arms, hands and upper extremity joints, arthritis, brain injuries, neurological diseases, stroke, and hearing impairment. Another exclusion criterion was the use of medication known to affect or alter cognition or neuromuscular performance.

Equipment description:

We used the Noraxon transmitter (TeleMyo 2400T G2) and receiver (TeleMyo 2400R G2) to collect the data. A lightweight, flexible goniometer (Noraxon 2-D Goniometer Sensor; Model ###) was used to collect the finger position data in order to calculate amplitude, frequency, and velocity of the movement. For the EMG recordings, we used EMG leads with disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon). For force measurements, we used a force transducer (TEDS IEEE 1451.4) that was incorporated into our custom-built platform and connected to a metal ring where the index finger was placed for flexor and extensor maximal voluntary isometric force measurements (Figures 1 and 2). All data was stored on a personal computer (Lenovo B570).

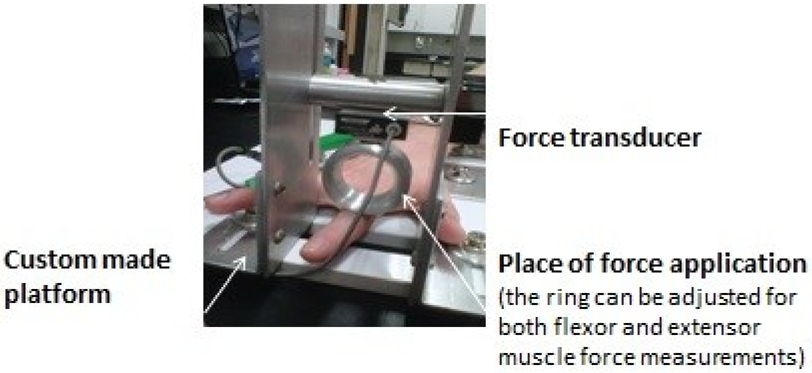


Figure 1. Photographic representation of the index finger placement to determine maximal voluntary isometric contraction of the extensors.

Electromyography

In preparation for EMG electrode placements, the skin surface was shaved and then cleaned with an alcohol swab. Surface EMG electrodes were attached to the prepared skin area over the flexor digitorum superficialis and extensor indicis proprius muscles on both right and left hands and forearms. A ground electrode was placed on the olecranon process of the ulna.

Goniometry

One plate of the 2-D electrical goniometer was placed on the medial part of the forearm immediately proximal to the wrist and the other plate was attached to the medial aspect of the index finger phalanges using double-sided tape. The goniometer also served as a splint to prevent any movement at the interphalangeal joints of the index finger. The participant was seated with the shoulder abducted at 30 degrees with the hand and forearm in pronation on the custom built platform that was positioned at the edge of a table.

Custom built platform apparatus:

The pronated hand and forearm was positioned on the platform so that the palm was secured firmly in the pronated position.

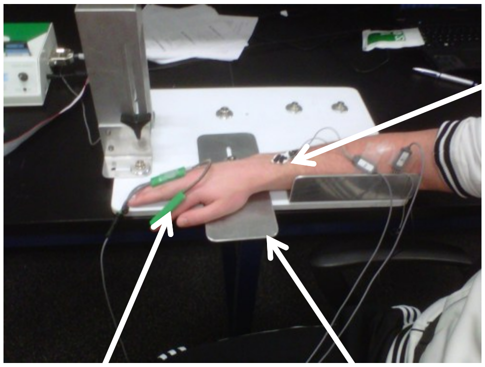


Figure 2. Photographic representation of the experimental set-up.

Kinematic and maximal voluntary contraction measurements

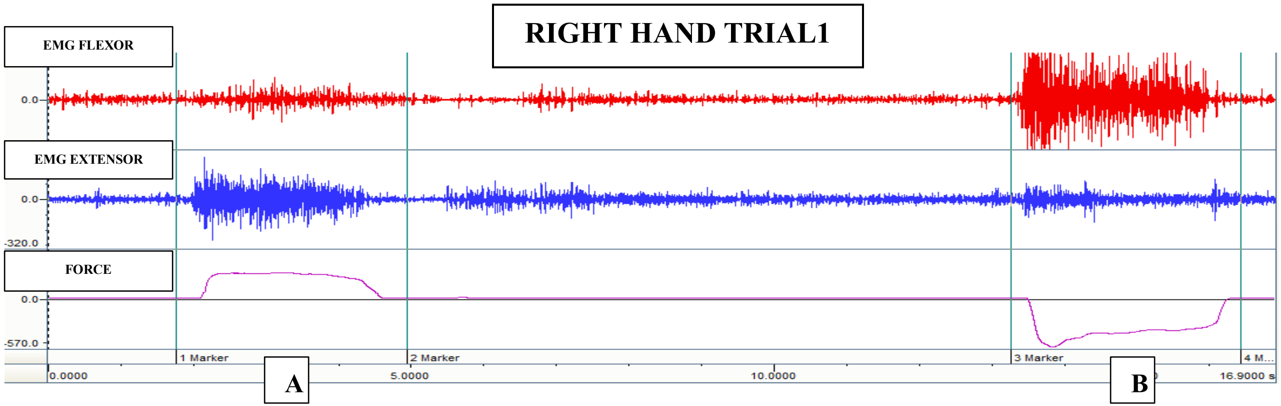
Maximal flexion / extension velocity was registered immediately prior (<5s) and after (<1s) the MVR task. The participants started in the neutral horizontal position and then flexed the index finger at the metacarpo-phalangeal joint downward as fast as possible in the comfortable range of motion (maximal flexion velocity). After a one second rest, they were instructed to bring the finger back to the neutral horizontal position as fast as possible (maximal extension velocity).

With the hand securely positioned on the platform, the participant was instructed to produce a maximal voluntary isometric contraction (MVIC) of the index finger flexors muscles by placing the distal metacarpo-phalangeal joint of the index finger on the force transducer ring for approximately 3 seconds. To measure MVIC of the index finger extensor muscles, the participant was asked to push up against the ring of the force transducer for 3 seconds. These measurements were obtained immediately before and after the 20-s MVR task (see experimental protocol for complete description)

Experimental Protocol

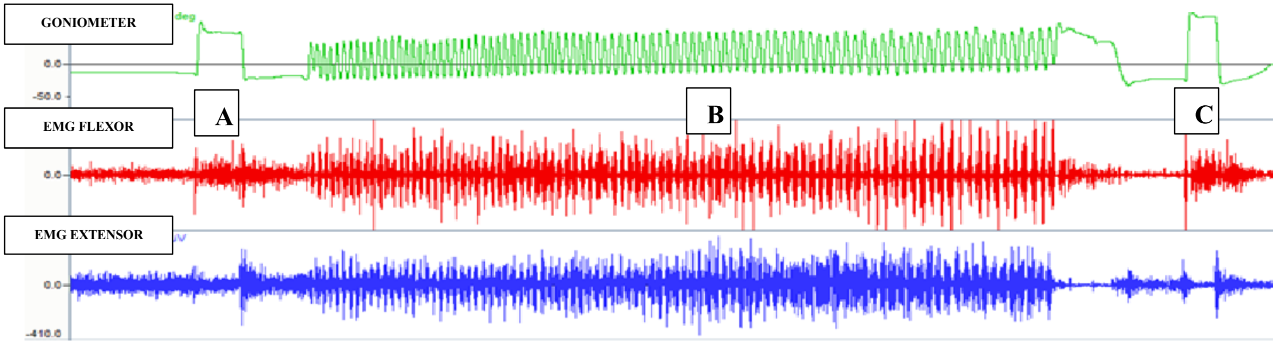
Figure 3. Sample of study protocol

RIGHT HAND TRIAL1



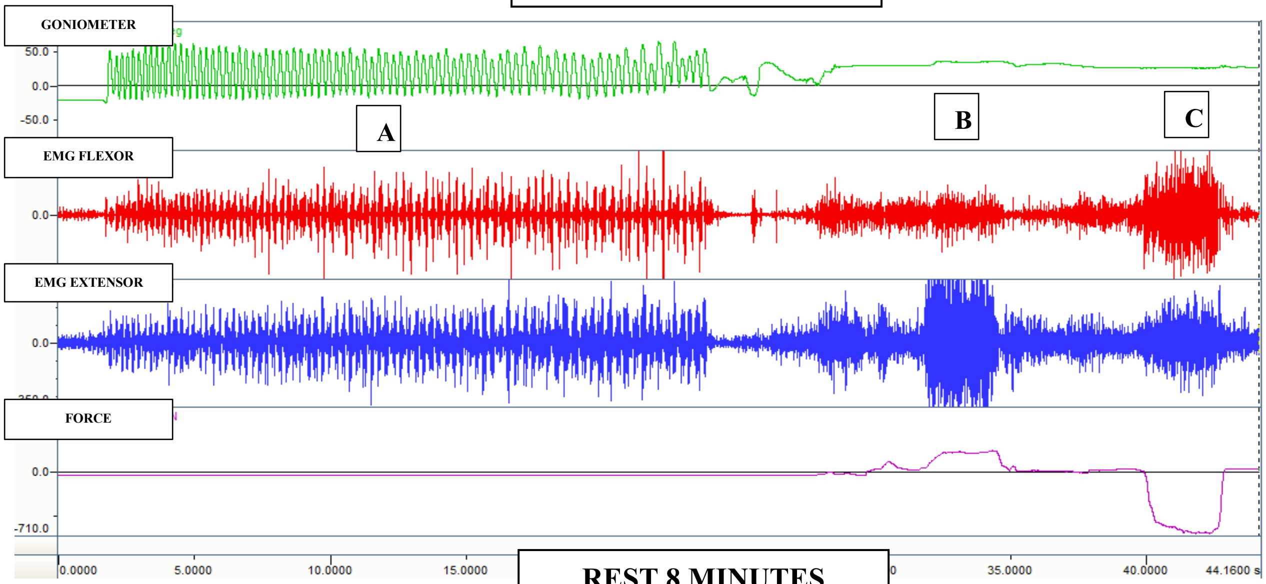
1. **Measurement of pre-task MVIC of extensor (A) and flexor (B)**

REST 2 MINUTES



2. **Measurement of maximal velocity pre-task (A), 20 s task (B), measurement of maximal velocity post-task (C)**

REST 1 MINUTE



3. **20 s task (A), measurement of MVIC of extensor (B) and flexor (C) post-task**

REST 8 MINUTES

TOTAL OF 3 TRIALS FOR EACH HAND

We recorded data from both the dominant and non-dominant hand in a randomized fashion with three trials repeated for each hand. Each trial started with the MVIC recordings of the flexors and extensors.

For the first trial that began two minutes after the completion of the force data collection, we asked the participant to complete the following: 1) maximally flex the finger once, 2) maximally extend the finger, 3) repeat the 20 s flexion / extension task, and 4) perform the maximal flexion / extension velocity assessment.

Following a one minute recovery period, participants were instructed to flex and extend the index finger as fast as possible through a self-selected range of motion for 20 seconds while attempting to maintain the rate of movement constant. Throughout the 20 s, we recorded their performance using the goniometer and the EMG system. Within five seconds of completing the described task, the post-task maximal flexion and extension forces were assessed as previously described using the force transducer.

The described procedure was performed three times on each hand. There was an eight-minute rest period between each trial and between the hands (Figure 3).

Data acquisition and analyses:

Continuous output from the goniometer and EMG was obtained throughout the entire 20 s MVR task. The kinematic variables of interest were frequency, amplitude, and peak velocity. Each flexion-extension cycle was labeled in Noraxon by identifying the time of occurrence of the beginning of cycle using 60% between the maximum and minimum positions from the goniometer and then all the data was transferred to MATLAB for further analysis using custom written scripts. From each recording, the first second was removed to account for the movement initiation. For the determination of frequency, the time period was identified between each two consecutive labels. By dividing one over the duration of each cycle, we obtained the frequency of each cycle measured in hertz (Hz). The MVR was divided into one-second periods and the frequency data for each cycle was averaged for each period.

Amplitude was calculated as the difference between the maximum and minimum points of the finger position for each cycle as recorded by the goniometer. The data was also averaged for each second.

For the calculation of peak velocity, we differentiated the position data of each cycle and then determined the maximum and minimum of the differentiation results to obtain the peak flexor and peak extensor velocity for each movement cycle. Data was later averaged for each second.

For the EMG analysis, we filtered the data using a band pass filter between 10 and 350 Hz and then calculated the root mean square (rms) for each cycle. Later, we calculated co-contraction using the following formula published by Rudolph, Axe & Snyder-Mackler (2000):

$$\text{Co-contraction Index} = (\text{rmsS}/\text{rmsL})*(\text{rmsS}+\text{rmsL});$$

where “rmsS” is the rms of the muscle that is less active at the moment and “rmsL” is the rms of the muscle that is more active. The results were averaged for each second. Finally, we calculated the power spectrum for each second and determined the median frequency.

All the results were later extracted from MATLAB and transferred to Excel. The statistical analysis was performed using SPSS software (SPSS Statistics version 20). Pre-post data for maximal velocity and maximal force were analysed with paired samples t-test. The differences in the young and older groups between pre and post data as well as demographic and anthropometric data were analysed using independent t-tests. Between- and within-group differences for amplitude, frequency, peak velocity, median frequency and co-contraction were performed during the following time intervals: 1) 1-4 seconds, 2) 5-9 seconds, 3) 10-14 seconds, and 4) 15-19 seconds. We used the repeated measures general linear model (2 x 4 ANOVA) for the inter- and intra-group comparisons. Paired sample t-tests (2-tailed, $P < 0.05$) were used to determine within group means comparisons. All data are presented as the mean ± standard error of the mean (SEM). All SPSS data tables for every trial are shown in Appendix 1.

Results

Group demographics

Twenty volunteers completed this study, with ten participants (two females and 8 males) in both the young and older groups. All values are expressed as the mean ± SEM. The average age of the young and older groups was 25.3±0.7 and 71.4± 1.8 years old, respectively. Height (young, 1.7± 0.02 m; older, 1.7 ± 0.02 m) and weight (young, 67.5 ± 2.9 kg; older, 73.5 ± 4.1 kg) were not different between the groups. The body mass index (BMI) for the groups did not differ significantly (young, 22.8 ±0.8; older, 24.9±1.0 kg/m^2). A measure of right hand dominance was determined using the Edinburgh Handedness Inventory (Oldfield, 1971). The indices of both groups (young, 72 ± 4.7; older, 85 ± 4.8) were calculated to be higher than the cut-off value of 40 used to verify right hand dominance.

Between group differences (Young vs. Older groups; dominant side)

As indicated by ANOVA, the two groups showed a significant group x time interaction for co-contraction (p=0.001) with the age effect accounting for 27% of the variance ($\eta^2 = 0.267$; Figure 3A) and peak velocity of the extensor muscle. The peak velocity of the extensor muscle demonstrated a significant group x time interaction as well (p=0.021) with the young group decreasing at a faster rate than the older group with age accounting for 16% of the variance ($\eta^2 = 0.163$; Figure 2D).

There was a significant main effect between groups for amplitude (p=0.033), peak velocity of the extensor (p=0.003) and peak velocity of the flexor (p=0.02) (Figure 2A, C, D). Post-hoc comparisons showed that these differences were maintained at every time interval (1-4, 5-9, 10-14, and 15-19 s) of the task. When comparing pre-task values for maximal flexor/extensor force and maximal flexor/extensor velocity, differences were found for maximal velocity of flexor between the young and the older groups (young, 1038± 64 degrees/sec; older, 815 ± 59 degrees/sec; p=0.019) and maximal force of flexor (young, 17 ± 2 N; older, 23 ± 2 N; p=0.047)(Figure 4A, B). For post-task comparisons, a difference was found for maximal velocity of flexor (young, 1052 ± 65 degrees/sec; older 811 ± 52 degrees/sec; p=0.012).

Young group (Dominant side)

MVR Finger movement

The frequency of movement gradually declined in this group from the beginning of the task until the end. The group started at 5.2 ± 0.24 Hz, then decreased the rate until 4.9 ± 0.22 (94% baseline, p=0.004) on the second time interval, continued slowing down during the third interval until 4.6 ± 0.25 Hz (88% baseline, p<0.001) and finished the task at 4.4 ± 0.25 (85% baseline, p p<0.001) (Figure 2B).

The amplitude was preserved for the first two time intervals, but then declined significantly by the third interval (from initial 64.8 ± 4.0 degrees to 61.3 ± 3.6 degrees, 94% baseline, p=0.055) and finally reduced until 59.4 ± 3.3 degrees on the final time zone (91% baseline, p=0.018)(Figure 2A). Peak velocity of both flexor and extensor was continuously declining from the beginning till the completion of the task (on the flexor side from 1274 ± 68.2 degrees/sec until 1009 ± 68.4 degrees/sec, 79% baseline, p<0.001; on the extensor from 1005 ± 53.2 degrees/sec until 776 ± 58.0 degrees/sec, 77% baseline, p<0.001)(Figure 2C, D).

Force and speed of single ballistic movements

We did not observe any change in maximal velocity or force in flexor or extensor following the completion of the 20 seconds task on the dominant side of the young group (Figure 4A, B).

EMG analysis

Median frequency of both flexor and extensor muscles demonstrated stability over time, with no significant difference observed between any time intervals. In addition, co-contraction did not change in this group over time (Figure 3B, C).

Older group (Dominant side)

MVR Finger movement

The frequency profile of this group declined gradually and significantly from the beginning of the task until the end. The frequency in this group started at 4.6 ± 0.17 Hz, reduced until 4.4 ± 0.17 Hz (94% baseline, p=0.001) in the second time interval, and further declined to the value of 4.2 ± 0.17 (89% baseline, p<0.001) at the third interval and finally reached 4.0 ± 0.15 Hz (85%

baseline, p<0.001) (Figure 2B). However, the amplitude was preserved in this group throughout the entire task (53.2 ± 3.8 degrees in the first time zone until 48.6 ± 3.2 degrees at the end)(Figure 2A).

The peak velocity of the flexor was declining continuously from 1044 ± 74 degrees/sec in the first interval to 934 ± 64.5 degrees/sec in the second (90% baseline, p=0.029) and 850 ± 68.4 degrees/sec in the third interval (81% baseline, p= 0.02) and finally reaching 801 ± 75 degrees/sec (77% baseline, p=0.016) at the end of the task (Figure 2C).

The change in peak velocity of the extensor from interval one to two demonstrated a trend (716 ± 42.6 degrees/sec to 678 ± 37.4 degrees/sec, p=0.062). By the third time interval, peak velocity was declining continuously, to 624 ± 39.1 degrees/sec (87% baseline, p=0.023) and 577± 47.2 degrees/sec (81% baseline, p=0.012) at the end of the task (Figure 2D).

Force and speed of single ballistic movements

We did not observe any change in maximal velocity or force in flexor or extensor following the completion of the 20 seconds task on the dominant side of the older group. (Figure 4)

EMG analysis

Similar to the situation observed for the young group on the dominant side, the older group did not demonstrate any shift in the median frequency of the dominant hand (Figure 3B, C). Median frequency of the flexor was 91.5 ± 5.2 Hz at the beginning and 90.2 ± 4.2 at the end of the task, with no significant shifts in between. Similar stability was present on the extensor side where the initial median frequency was 88.7 ± 4.2 Hz and reached 86.6 ± 4.9 Hz at the end with no significant shifts. The dynamic of co-contraction in this group however followed a quite different path as compared to the young adults. Co-contraction started to increase from the beginning of the task and progressively rose throughout the 20 s. At the initiation of the task, the co-contraction index was 87 ± 13 for this group, at the second time interval it reached 94 ±14 (108% baseline, p=0.013), later becoming 106 ± 15 (122% of baseline, p=0.001) in the third interval and finally 109 ± 14 at the end of the task (125% of baseline, p<0.001)(Figure 3A).

Young vs. Older groups (Non-dominant)

Although no group x time interaction was found, there was a main effect of the group differences with respect to amplitude (p=0.022), peak velocity of the extensor (p=0.005), peak velocity of flexor (p=0.035), and the median frequency of the extensors (p=0.004 in general, different on every time interval) (Figure 5A, C, D). Post-hoc differences were found in these parameters at all time intervals. The pre-post values for maximal flexor/extensor force and maximal flexor/extensor velocity did not differ between groups (Figure 4C, D).

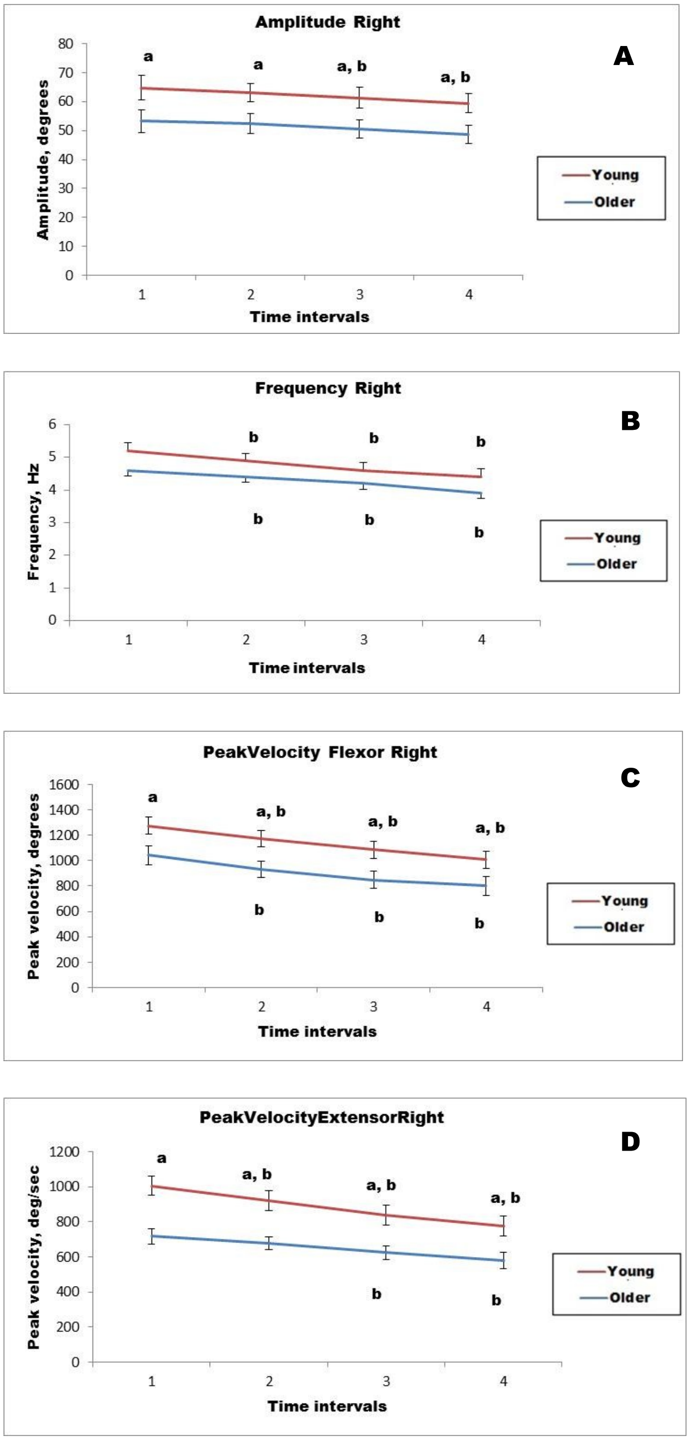


Figure 4. Kinematic measures of the dominant index finger throughout the 20-second task

Changes in amplitude (A), frequency (B), peak velocity of the flexor (C) and extensor (D) of the dominant index finger in young (red) and older group (blue) during a 20-s maximal voluntary rate task. Measurements were obtained continuously over time and expressed in 4 time intervals (interval 1, 1-4 s; interval 2, 5-9 s; interval 3, 10-14 s; interval 4, 15-19)

[a] Significant difference between group means at each respective time interval

[b] Significant difference from the initial time interval

All values are expressed as means ± SEM; n=10 per group.

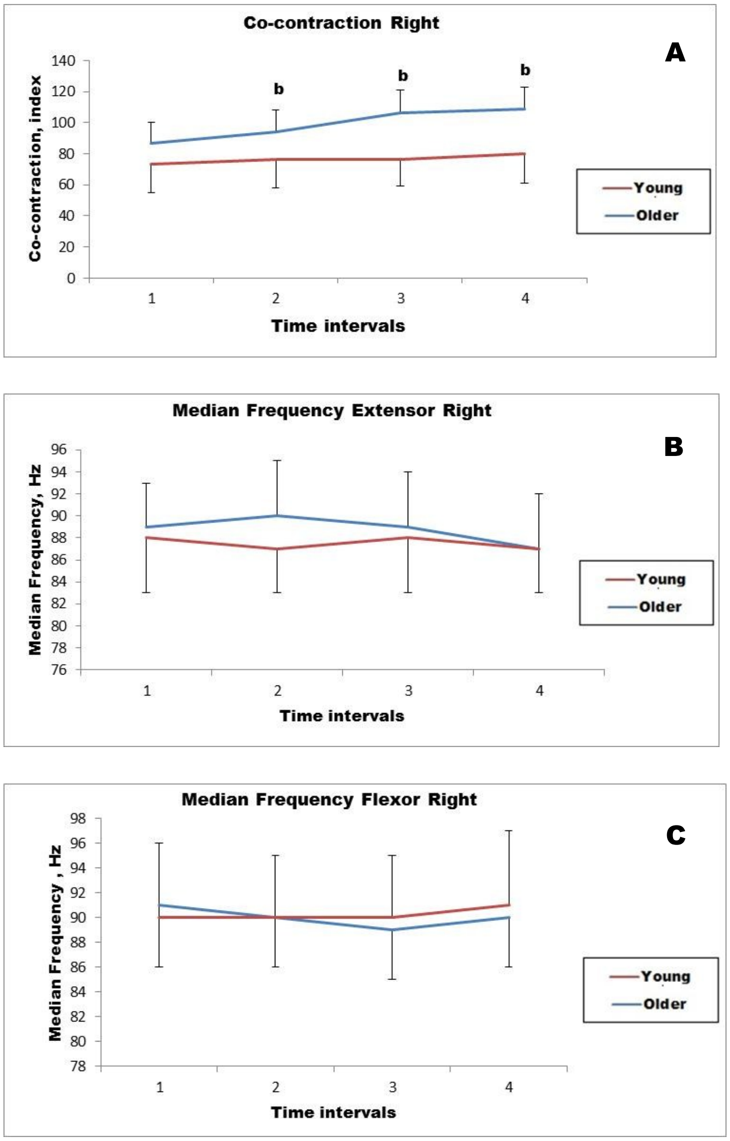


Figure 5. Electromyographic measures of the dominant index finger throughout the 20-second task

Changes in co-contraction (A), median frequency of extensor (B) and median frequency of flexor (C) of the dominant index finger in young (red) and older group (blue) during a 20-s maximal voluntary rate task. Measurements were obtained continuously over time and expressed in 4 time intervals (interval 1, 1-4 s; interval 2, 5-9 s; interval 3, 10-14 s; interval 4, 15-19)

[a] Significant difference between group means at each respective time interval

[b] Significant difference from the initial time interval

All values are expressed as means ± SEM; n=10 per group.

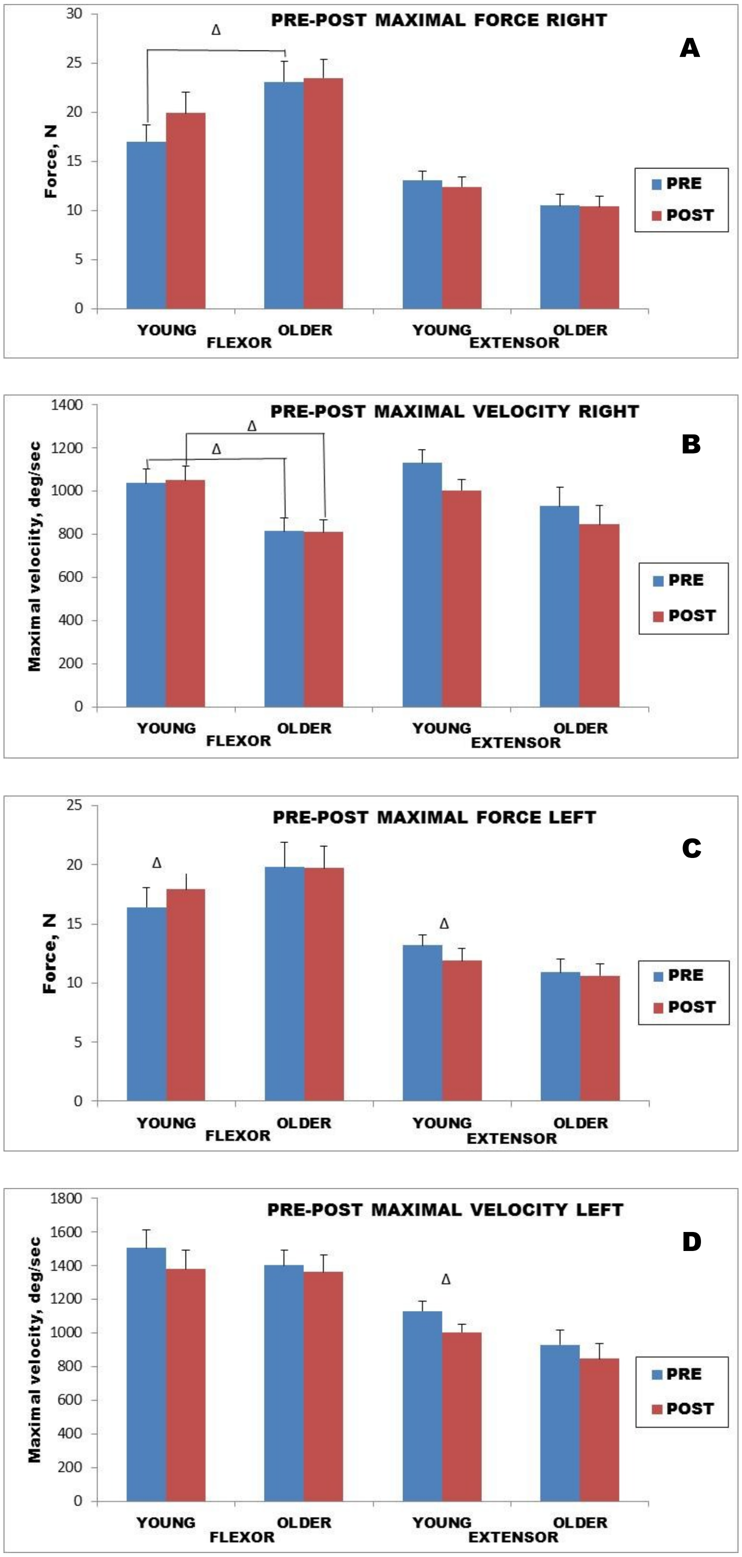


Figure 6. Pre-post task kinematic measures on of the dominant and non-dominant index finger

Pre (blue)-post (red) changes in maximal force (A), maximal velocity (B) of the dominant index finger and maximal force (C) and maximal velocity (D) of the non-dominant index finger in young and older group during a 20-s maximal voluntary rate task. Measurements were obtained immediately before and after the 20 s of the task for the maximal velocity and 2 min before and immediately after the 20 s task for the maximal force. $^{\Delta}$ Significantly different ($p \leq 0.05$) between groups. All values are expressed as means ± SEM; n=10 per group.

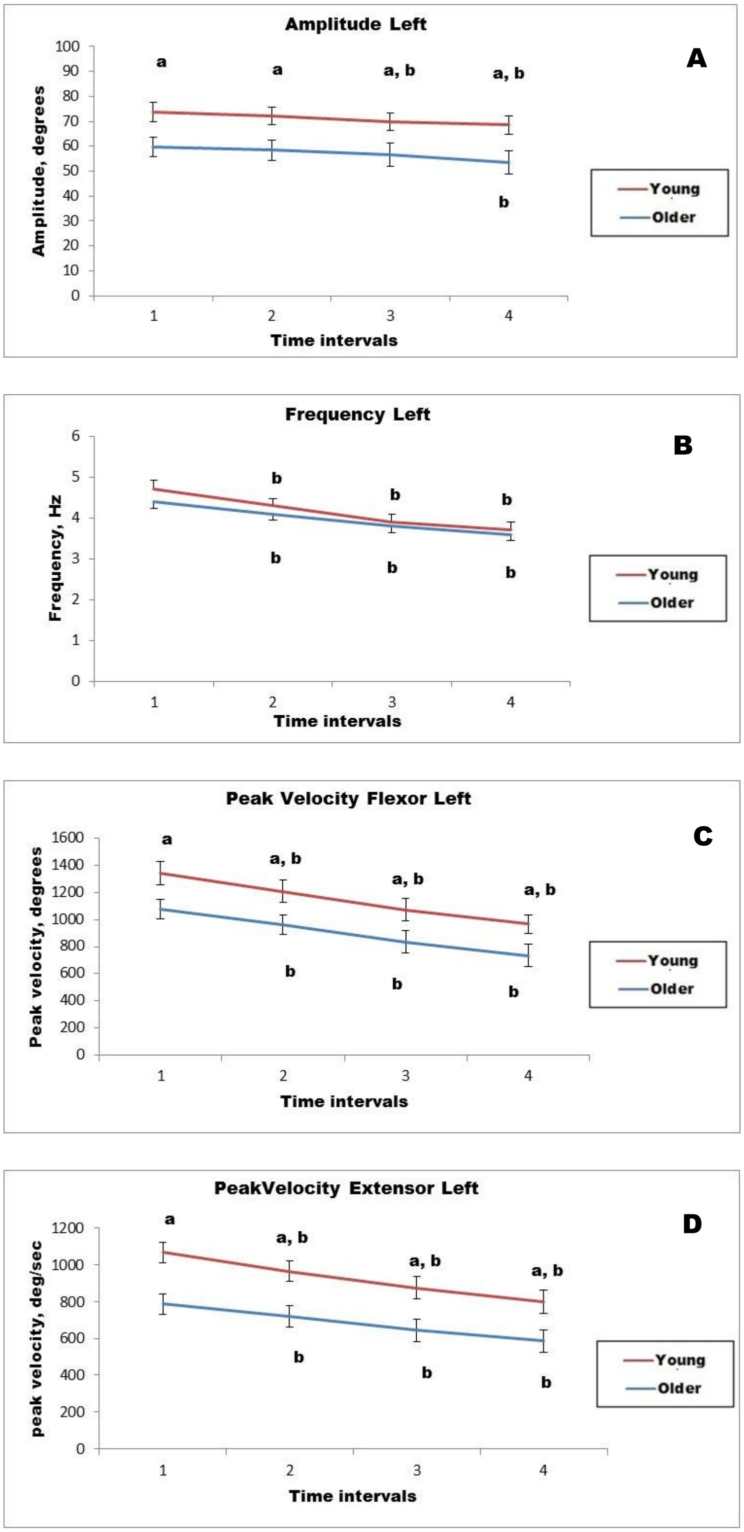


Figure 7. Kinematic measures of the non-dominant index finger throughout the 20-second task

Changes in amplitude (A), frequency (B), peak velocity of the flexor (C) and extensor (D) of the non-dominant index finger in young (red) and older group (blue) during a 20-s maximal voluntary rate task. Measurements were obtained continuously over time and expressed in 4 time intervals (interval 1, 1-4 s; interval 2, 5-9 s; interval 3, 10-14 s; interval 4, 15-19)

[a] Significant difference between group means at each respective time interval

[b] Significant difference from the initial time interval

All values are expressed as means ± SEM; n=10 per group.

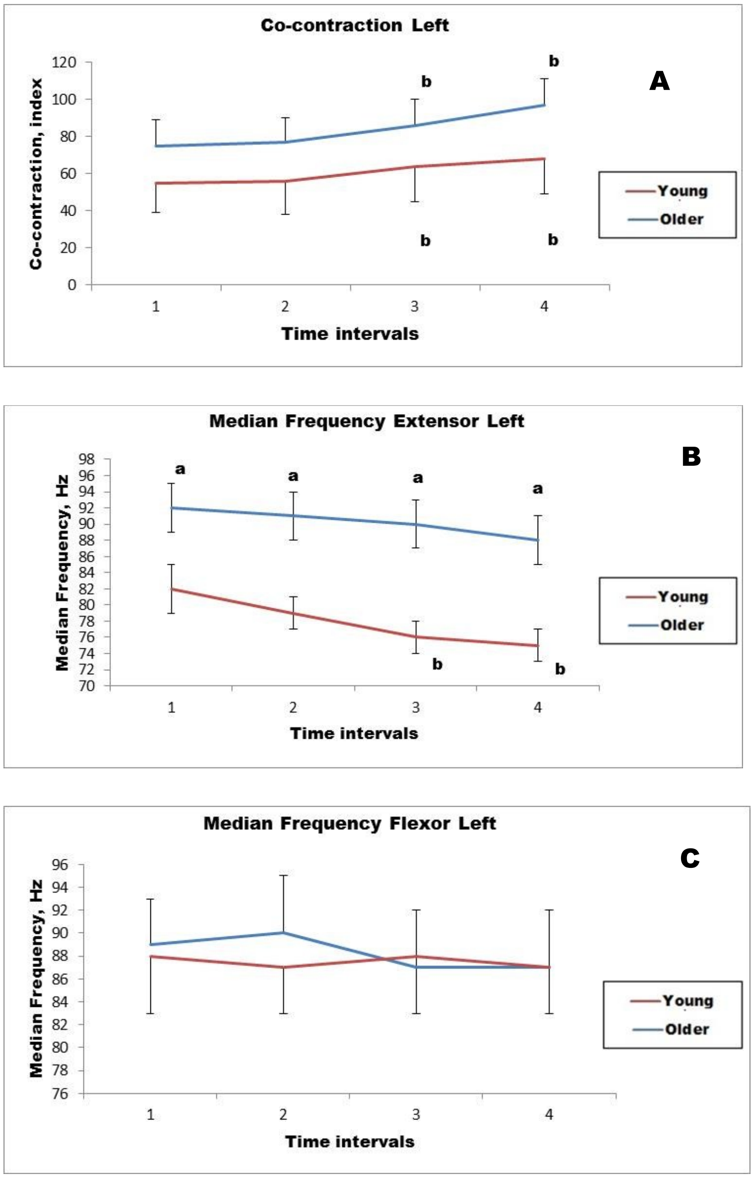


Figure 8. Electromyographic measures of the non-dominant index finger throughout the 20-second task

Changes in co-contraction (A), median frequency of extensor (B) and median frequency of flexor (C) of the non-dominant index finger in young (red) and older group (blue) during a 20-s maximal voluntary rate task. Measurements were obtained continuously over time and expressed in 4 time intervals (interval 1, 1-4 s; interval 2, 5-9 s; interval 3, 10-14 s; interval 4, 15-19)

[a] Significant difference between group means at each respective time interval

[b] Significant difference from the initial time interval

All values are expressed as means ± SEM; n=10 per group.

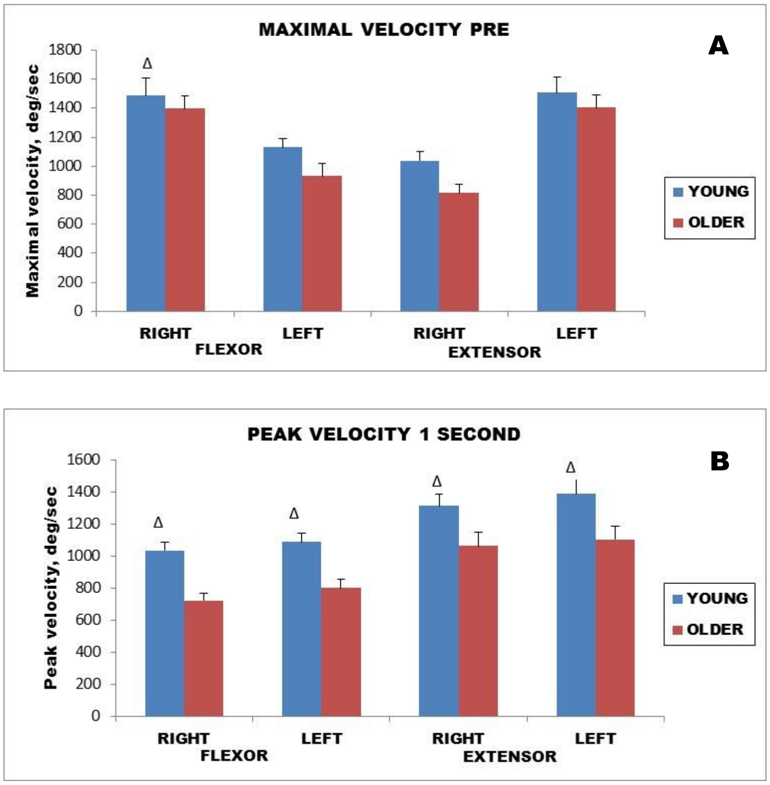


Figure 9. Comparison of index finger maximal velocity and peak velocity of the first second of the trial

Differences in dominant and non-dominant index finger maximal velocity (A) and peak velocity of the first second of the trial (B) between young (blue) and older (red) groups. Measurements were obtained immediately before the 20 s task for maximal velocity and at the first second of the 20 s task for peak velocity.

$^{\Delta}$ Significant difference between group means

All values are expressed as means ± SEM; n=10 per group.

Young group (Non-dominant)

MVR Finger movement

We observed a steady decline in movement frequency in the non-dominant hand of the young group starting from the beginning of the movement (Figure 5B). The frequency declined from the initial value of 4.70 ± 0.22 Hz to 4.32 ± 0.18 Hz (89% of baseline, $p<0.001$) and further to 3.94 ± 0.20 (84% of baseline, $p<0.001$) and finally to 3.69 ± 0.21 Hz (79% baseline, $p<0.001$). The amplitude started to drop at the third time interval from the initial value of 73.68± 3.8 degrees to 69.83 ± 3.6 (95% of baseline, $p=0.004$) and further to 68.48 ± 3.7 degrees (93% of baseline, $p<0.001$) in the last time interval (Figure 5A).

Peak velocity for both flexor and extensor was declining from the beginning of the task at each time interval until the end. On the flexor side, starting from a value of 1341± 87.7 degrees/sec and until 967± 69.7 degrees/sec (72% of baseline, $p<0.001$) at the end of the task and on the extensor side, from a value of 1066 ± 56.0 degrees/sec until 798 ± 61.8 degrees/sec in the fourth time interval (75% of baseline, $p<0.001$)(Figure 5C, D).

Force and speed of single ballistic movements

Maximal force of the flexor increased from 16.4 ± 1.7 to 17.9± 2.1 N (109% of baseline, $p=0.046$) and MVC extensor declined from 13.2 ± 0.9 to 11.9 ± 1.0 N (90% of baseline, $p=0.037$) (Figure 4C, D). Maximal velocity of extensor also decreased significantly in the non-dominant extensor in the young group from 1129.3 ± 62.2 to 1003.8 ± 48.6 degrees/sec (89% of baseline, $p=0.009$).

EMG analysis

Median frequency appeared to be quite stable for the flexor, with no significant shift throughout the entire task (Figure 6C). However, we observed a significant decrease in the median frequency of the non-dominant extensor in the young group at the third and fourth time intervals (Figure 6B). The median frequency shifted from the initial 81.8± 3.3 Hz to 76 ± 2.1 Hz (93%, p=0.03) and later to 75.3± 2.4 Hz (92% of baseline, p=0.031). The co-contraction index increased during the later stages of the task, gaining significance at the third time interval and continuing to rise until the end of the task (54.8 ± 16.0 at the beginning to 64.5 ± 18.8, 117% of baseline, p=0.015 and reaching 68 ± 18.9, 124% of baseline, p=0.004)(Figure 6A).

Old group (Non-dominant)

MVR Finger movement

The older group had a similar behaviour on the non-dominant side as the young group with the frequency gradually declining from the beginning of the task until the end (Figure 5B). The frequency at the first time interval was 4.4± 0.16 Hz and then decreased to 4.1± 0.16 Hz (93% of baseline, p=0.004), in the third time zone to 3.8± 0.16 Hz (86% of baseline, p<0.001) and finally to 3.6 ± 0.14 Hz (82% of baseline, p<0.001). However, the amplitude in this category was preserved until the last time interval (59.6 ± 3.9 degrees at the beginning and declining to 53.4 ± 4.7 in the fourth time interval). Peak velocity of both flexor and extensor behaved similar to the younger group, with both parameters declining throughout the entire task (flexor from 1075 ± 71.2 degrees/sec to 733 ± 82.1 degrees/sec, 68% of baseline, p<0.001) and the extensor from 787 ± 47.9 degrees/sec to 585 ± 55.1 degrees/sec, 74% of baseline, p=0.001)(Figure 5C, D).

Force and speed of single ballistic movements

We observed no difference in the maximal force pre-post task in the non-dominant hand of the older group (see Figure 4). The only trend (p=0.071) that was noticed was a downward drop in the maximal velocity of the extensor, from an initial 1129 ± 62.2 degrees/sec to 1004 ± 48.6 degrees/sec immediately post-task (Figure 4D).

EMG analysis

Similar to the young group, median frequency of the flexor was very consistent in this group, with no change from the initial time period (88.9 ± 4.2) to the final interval (86.6± 4.9) (Figure 6C). The index of co-contraction increased over time, similar to the young group, starting from the third (86.2 ± 13.9, 115% of baseline, p=0.004) and fourth time intervals (96.9 ± 14.1, 130% of baseline, p<0.001) (Figure 6A).

Pre-task maximal velocity and peak velocity at 1 sec into the task

With the exception of the significant difference (p=0.019) observed between groups with respect to the pre-task maximal velocity of the dominant flexors, no other differences exist between groups, neither in the non-dominant flexor nor the dominant and non-dominant extensors (Figure 7A). However, peak velocity measurements taken 1s into the task revealed significant between group differences in dominant (p=0.042) and non-dominant (p=0.033) flexors as well as the dominant (p=0.001) and non-dominant (p=0.02) extensors (Figure 7B).

Discussion

The measurement and assessment of MVR is essential to our understanding of the limiting factors associated with motor control of human movement. The purpose of this study was to test the capacity of a specific MVR task in order to detect any age-related differences of the motor system. This particular movement task was selected because it incorporates the index finger that is commonly used in today's technological environment. Considering the chronic and repetitive use of electronic devices known to incorporate flexion and extension of the dominant index finger, and to a much lesser extent the non-dominant finger, we thought that this was a relevant and representative task that both young and older groups can successfully complete.

As expected, we observed that the subjects in both young and older groups were unable to maintain their maximal frequency of index finger movement; beginning within the initial 4 s interval and continuing to decline throughout the remainder of the 20-s task. Although the subjects were all instructed to maintain their frequency constant, both groups were unable to comply with the task directive. The rates of decline were similar between groups since there were no interactions observed. In fact, our actual values including the magnitude of the rate of change in the frequency and peak velocity recordings of the flexor and extensor muscles were remarkably similar to those of Rodrigues et al. (2009). Amplitude was maintained during the initial 10 s and gradually declined in the last half of our task whereas, in the Rodrigues group, amplitude was maintained throughout the task. The reason for the discrepancy between our two studies is not readily apparent.

As hypothesized, the MVR task revealed age-related differences on the dominant side. We observed a significant interaction for selective variables describing the kinematics (e.g., peak velocity extensor) and muscle activation pattern (e.g., co-contraction). The older group demonstrated a progressive increase in co-contraction over time whereas, the younger group maintained their initial level throughout the entire 20-s task. It must be noted that the age effect accounted for 27% of the variance. To date, only one published study has described the transition from a tri-phasic pattern to a greater expression of co-contraction over the same 20-s MVR task (Rodrigues et al., 2009). Unfortunately, we cannot draw any conclusion in terms of co-contraction dynamics over time from their findings as they only conducted a visual inspection of their results. The peak velocity of the extensor muscle demonstrated a significant interaction as well, with the young group decreasing at a faster rate than the older group with age describing 16% of the variance. This is a novel, age-related difference that supports our original hypothesis.

It is remarkable that the non-dominant side demonstrated no significant interactions indicating that the two groups appear to behave in a more similar pattern. The literature describing the phenomenon of learning a new motor task in both young and old could explain our findings (Wu & Hallett, 2005). The movement task of the index finger is comparably new for both groups when performed on the non-dominant hand and additional brain activation is expected to be present during the learning process. However, the extended area of brain activation is more common in the routine of the older people and therefore does not bring about any additional sense of effort. This difference in new task perception might be counterbalancing the age related differences that were revealed on the dominant side.

When examining the magnitude of the individual parameters between the groups, both dominant and non-dominant side demonstrate differences in amplitude and peak velocity of the flexor and extensor. In all the described situations, the young group demonstrated significantly higher values. The only parameter that showed significant difference between the groups unilaterally was the median frequency of the extensor muscle on the non-dominant side. However, in order to interpret this finding, it is essential to view it in context with our pre-post data.

As we know, the absence of a difference between the pre-post MVC and maximal velocity measurements is an indicator that a task is peripheral fatigue free. However, the pre-post difference can be originating from both the periphery and the centre. For the older group on both dominant and non-dominant sides as well as the young group on the dominant side, the task was peripheral fatigue free, that is the force generating capacity and the ability to generate maximal velocities was not affected by our task. However, this was not true for the non-dominant side of the young group. We observed the decline in force generating capacity that could be indicative of selective fatigue of fast twitch fibres on the non-dominant side. The earlier mentioned shift of the median frequency of the extensor muscle on the non-dominant side in the young group is just another indication for the presence of fatigue. So why did this group experience fatigue on the non-dominant side and not the dominant side? Or, why is that that only the young group and not the old develop this fatigue on the non-dominant side? If we go back to our proposed hypothetical explanation, the young group is "less comfortable" for the compensation that is most common for the older people in terms of the additional brain activation. This might be taking more energy and time and as a result bring about a higher level of central fatigue that we observed.

We would like to return to the pre-programed nature of the MVR task described in the literature. One of the observations we have made is supportive of this point. When comparing the maximal velocity recorded immediately prior to the task and the peak velocity in the first second of the analyzed data, we observed an interesting pattern. Maximal velocity was only different between the groups for the flexor of the dominant hand; however, the peak velocity was consistently different for all the four combinations (flexor and extensor, dominant and non-dominant). This is a very curious observation as the two recordings were separated by less than two seconds. We propose that it is the nature of the motor control that revealed such a strong age-related difference. The planning of a 20-s repetitive maximal velocity flexion/extension task is not the same as a collection of individual maximal velocity flexion/extension tasks put together. It is when the continuous maximal effort is about to be involved that we can observe the age-related difference demonstrated by this observation. This adds to the value and significance of the model used and to its precision in detecting the differences otherwise overlooked by single effort tests.

Conclusions:

We have applied the MVR task implemented by Rodrigues et al., (2009) to an elderly population and we have extended the findings to include group comparisons of young and older individuals. This model appears to be sensitive to the influence of age and allows us to make continuous observations as opposed to those tasks (e.g., MVC) that allow for only single or discrete observations of force. We can conclude that this particular MVR task challenges the central limits of the motor system differently with age, not only in the way that the two groups respond in terms of movement kinematics and patterns of muscle activation but also in the way that elderly appear to pre-program their maximal voluntary movements. We can also conclude that hand dominance plays a differential role in the outcome of the MVR task in that the non-dominant side adjusts differently to the MVR in terms of peak velocity and median frequency (extensors) and that the young appear to experience a peripheral form of fatigue that is not seen in the elderly.

Now that we have gathered normative data for an elderly group, we are in a better position to extend the scope of our studies to include those clinical groups (e.g., Parkinson's disease, stroke patients, cancer patients) who are aged and dealing with a disease state or condition that is already challenging the homeostatic limits of the motor system.

"We have not succeeded in answering all our problems. The answers we have found only serve to raise a whole set of new questions. In some ways, we feel we are as confused as ever, but we believe we are confused on a higher level and about more important things". C. Kelley, "The Workshop Way of Learning", 1951

References

Aniansson, A., Hedberg, M., Henning, G. B., & Grimby, G. (1986). Muscle morphology, enzymatic activity, and muscle strength in elderly men: A follow-up study. *Muscle & Nerve, 9*(7), 585-591. doi: 10.1002/mus.880090702

Arbogast, S., Vassilakopoulos, T., Darques, J. L., Duvauchelle, J. B., & Jammes, Y. (2000). Influence of oxygen supply on activation of group IV muscle afferents after low-frequency muscle stimulation. *Muscle & Nerve, 23*(8), 1187-1193.

Arias, P., Robles-Garcia, V., Espinosa, N., Corral, Y., & Cudeiro, J. (2012). Validity of the finger tapping test in Parkinson's disease, elderly and young healthy subjects: Is there a role for central fatigue? *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology,* doi: 10.1016/j.clinph.2012.04.001

Balice-Gordon, R. J. (1997). Age-related changes in neuromuscular innervation. *Muscle & Nerve.Supplement, 5*, S83-7.

Benwell, N. M., Mastaglia, F. L., & Thickbroom, G. W. (2006). Reduced functional activation after fatiguing exercise is not confined to primary motor areas. *Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 175*(4), 575-583. doi: 10.1007/s00221-006-0573-9

Bigland-Ritchie, B. R., Dawson, N. J., Johansson, R. S., & Lippold, O. C. (1986). Reflex origin for the slowing of motoneurone firing rates in fatigue of human voluntary contractions. *The Journal of Physiology, 379*, 451-459.

Bongiovanni, L. G., & Hagbarth, K. E. (1990). Tonic vibration reflexes elicited during fatigue from maximal voluntary contractions in man. *The Journal of Physiology, 423*, 1-14.

Ceballos, D., Cuadras, J., Verdu, E., & Navarro, X. (1999). Morphometric and ultrastructural changes with ageing in mouse peripheral nerve. *Journal of Anatomy, 195 (Pt 4)*(Pt 4), 563-576.

Chan, K. M., Raja, A. J., Strohschein, F. J., & Lechelt, K. (2000). Age-related changes in muscle fatigue resistance in humans. *The Canadian Journal of Neurological Sciences.Le Journal Canadien Des Sciences Neurologiques, 27*(3), 220-228.

Cousins, M. S., Corrow, C., Finn, M., & Salamone, J. D. (1998). Temporal measures of human finger tapping: Effects of age. *Pharmacology, Biochemistry, and Behavior, 59*(2), 445-449.

Crenshaw, A. G., Karlsson, S., Gerdle, B., & Friden, J. (1997). Differential responses in intramuscular pressure and EMG fatigue indicators during low- vs. high-level isometric contractions to fatigue. *Acta Physiologica Scandinavica, 160*(4), 353-361.

Darques, J. L., Decherchi, P., & Jammes, Y. (1998). Mechanisms of fatigue-induced activation of group IV muscle afferents: The roles played by lactic acid and inflammatory mediators. *Neuroscience Letters, 257*(2), 109-112.

Di Lazzaro, V., Oliviero, A., Tonali, P. A., Mazzone, P., Insola, A., Pilato, F., . . . Rothwell, J. C. (2003). Direct demonstration of reduction of the output of the human motor cortex induced by a fatiguing muscle contraction. *Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 149*(4), 535-538. doi: 10.1007/s00221-003-1408-6

Dobkin, B. H. (2008). Fatigue versus activity-dependent fatigability in patients with central or peripheral motor impairments. *Neurorehabilitation and Neural Repair, 22*(2), 105-110. doi: 10.1177/1545968308315046

Doherty, T. J., Vandervoort, A. A., & Brown, W. F. (1993). Effects of ageing on the motor unit: A brief review. *Canadian Journal of Applied Physiology ; Revue Canadienne De Physiologie Appliquee, 18*(4), 331-358.

Duchateau, J., & Hainaut, K. (1993). Behaviour of short and long latency reflexes in fatigued human muscles. *The Journal of Physiology, 471*, 787-799.

Einsiedel, L. J., & Luff, A. R. (1992). Alterations in the contractile properties of motor units within the ageing rat medial gastrocnemius. *Journal of the Neurological Sciences, 112*(1-2), 170-177.

Einsiedel, L. J., & Luff, A. R. (1992). Effect of partial denervation on motor units in the ageing rat medial gastrocnemius. *Journal of the Neurological Sciences, 112*(1-2), 178-184.

Fujisawa, K. (1976). Some observations on the skeletal musculature of aged rats-III. abnormalities of terminal axons found in motor end-plates. *Experimental Gerontology, 11*(1-2), 43-47.

Gandevia, S. C. (1996). Insights into motor performance and muscle fatigue based on transcranial stimulation of the human motor cortex. *Clinical and Experimental Pharmacology & Physiology, 23*(10-11), 957-960.

Gandevia, S. C. (1998). Neural control in human muscle fatigue: Changes in muscle afferents, motoneurones and motor cortical drive [corrected. *Acta Physiologica Scandinavica, 162*(3), 275-283.

Gandevia, S. C., Allen, G. M., Butler, J. E., & Taylor, J. L. (1996). Supraspinal factors in human muscle fatigue: Evidence for suboptimal output from the motor cortex. *The Journal of Physiology, 490 (Pt 2)*(Pt 2), 529-536.

Gandevia, S. C., Allen, G. M., & McKenzie, D. K. (1995). Central fatigue. critical issues, quantification and practical implications. *Advances in Experimental Medicine and Biology, 384*, 281-294.

Gardiner, P. (2001). Neuromuscular aspects of physical activity. Human Kinetics, Champaign, IL.

Garland, S. J., & McComas, A. J. (1990). Reflex inhibition of human soleus muscle during fatigue. *The Journal of Physiology, 429*, 17-27.

Gutmann, E., & Hanzlikova, V. (1973). Basic mechanisms of aging in the neuromuscular system. *Mechanisms of Ageing and Development, 1*(5), 327-349.

Heuninckx, S., Wenderoth, N., Debaere, F., Peeters, R., & Swinnen, S. P. (2005). Neural basis of aging: The penetration of cognition into action control. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience, 25*(29), 6787-6796. doi: 10.1523/JNEUROSCI.1263-05.2005

Hultborn, H., Lipski, J., Mackel, R., & Wigstrom, H. (1988). Distribution of recurrent inhibition within a motor nucleus. I. Contribution from slow and fast motor units to the excitation of Renshaw cells. *Acta Physiologica Scandinavica, 134*(3), 347-361.

Jang, Y. C., Lustgarten, M. S., Liu, Y., Muller, F. L., Bhattacharya, A., Liang, H., . . . Van Remmen, H. (2010). Increased superoxide in vivo accelerates age-associated muscle atrophy through mitochondrial dysfunction and neuromuscular junction degeneration. *FASEB Journal : Official Publication of the Federation of American Societies for Experimental Biology, 24*(5), 1376-1390. doi: 10.1096/fj.09-146308

Jimenez-Jimenez, F. J., Calleja, M., Alonso-Navarro, H., Rubio, L., Navacerrada, F., Pilo-de-la-Fuente, B., . . . Agundez, J. A. (2011). Influence of age and gender in motor performance in healthy subjects. *Journal of the Neurological Sciences, 302*(1-2), 72-80. doi: 10.1016/j.jns.2010.11.021

Karni, A., Meyer, G., Jezzard, P., Adams, M.M., Turner, R., Ungerleider, L.G. (1995). Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature,* 377, 155–158.

Kaufman, M. P., Rybicki, K. J., Waldrop, T. G., & Ordway, G. A. (1984). Effect of ischemia on responses of group III and IV afferents to contraction. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 57*(3), 644-650.

Kawamura, Y., O'Brien, P., Okazaki, H., & Dyck, P. J. (1977b). Lumbar motoneurons of man II: The number and diameter distribution of large- and intermediate-diameter cells in "motoneuron columns" of spinal cord of man. *Journal of Neuropathology and Experimental Neurology, 36*(5), 861-870.

Kawamura, Y., Okazaki, H., O'Brien, P. C., & Dych, P. J. (1977a). Lumbar motoneurons of man: I) number and diameter histogram of alpha and gamma axons of ventral root. *Journal of Neuropathology and Experimental Neurology, 36*(5), 853-860.

Kluger, B. M., Palmer, C., Shattuck, J. T., & Triggs, W. J. (2012). Motor evoked potential depression following repetitive central motor initiation. *Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 216*(4), 585-590. doi: 10.1007/s00221-011-2962-y

Lentz, M., & Nielsen, J. F. (2002). Post-exercise facilitation and depression of M wave and motor evoked potentials in healthy subjects. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology, 113*(7), 1092-1098.

Lexell, J., Downham, D., & Sjostrom, M. (1983). Distribution of different fibre types in human skeletal muscles. A statistical and computational model for the study of fibre type grouping and early diagnosis of skeletal muscle fibre denervation and reinnervation. *Journal of the Neurological Sciences, 61*(3), 301-314.

Lexell, J., Downham, D., & Sjostrom, M. (1987). Morphological detection of neurogenic muscle disorders: How can statistical methods aid diagnosis? *Acta Neuropathologica, 75*(2), 109-115.

Lexell, J., & Downham, D. Y. (1991). The occurrence of fibre-type grouping in healthy human muscle: A quantitative study of cross-sections of whole vastus lateralis from men between 15 and 83 years. *Acta Neuropathologica, 81*(4), 377-381.

Lexell, J., Taylor, C. C., & Sjostrom, M. (1988). What is the cause of the ageing atrophy? total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *Journal of the Neurological Sciences, 84*(2-3), 275-294.

Luders, H. O. (1996). The supplementary sensorimotor area. An overview. *Advances in Neurology, 70*, 1-16.

Macefield, G., Hagbarth, K. E., Gorman, R., Gandevia, S. C., & Burke, D. (1991). Decline in spindle support to alpha-motoneurones during sustained voluntary contractions. *The Journal of Physiology, 440*, 497-512.

Maier, M. A., Bennett, K. M., Hepp-Reymond, M. C., & Lemon, R. N. (1993). Contribution of the monkey corticomotoneuronal system to the control of force in precision grip. *Journal of Neurophysiology, 69*(3), 772-785.

Martin, P. G., Smith, J. L., Butler, J. E., Gandevia, S. C., & Taylor, J. L. (2006). Fatigue-sensitive afferents inhibit extensor but not flexor motoneurons in humans. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience, 26*(18), 4796-4802. doi: 10.1523/JNEUROSCI.5487-05.2006

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Das, S., Callicott, J. H., & Weinberger, D. R. (2002). Neurophysiological correlates of age-related changes in human motor function. *Neurology, 58*(4), 630-635.

Miller, R. G., Kent-Braun, J. A., Sharma, K. R., & Weiner, M. W. (1995). Mechanisms of human muscle fatigue. Quantitating the contribution of metabolic factors and activation impairment. *Advances in Experimental Medicine and Biology, 384*, 195-210.*Q*

Mittal, K. R., & Logmani, F. H. (1987). Age-related reduction in 8th cervical ventral nerve root myelinated fiber diameters and numbers in man. *Journal of Gerontology, 42*(1), 8-10.

Nutt, J. G., Lea, E. S., Van Houten, L., Schuff, R. A., & Sexton, G. J. (2000). Determinants of tapping speed in normal control subjects and subjects with Parkinson's disease: Differing effects of brief and continued practice. *Movement Disorders : Official Journal of the Movement Disorder Society, 15*(5), 843-849.

Oda, K. (1984). Age changes of motor innervation and acetylcholine receptor distribution on human skeletal muscle fibres. *Journal of the Neurological Sciences, 66*(2-3), 327-338.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*(1), 97-113.

Prakash, Y. S., & Sieck, G. C. (1998). Age-related remodelling of neuromuscular junctions on type-identified diaphragm fibers. *Muscle & Nerve, 21*(7), 887-895.

Rangaraju, S., Hankins, D., Madorsky, I., Madorsky, E., Lee, W. H., Carter, C. S., . . . Notterpek, L. (2009). Molecular architecture of myelinated peripheral nerves is supported by calorie restriction with aging. *Aging Cell, 8*(2), 178-191. doi: 10.1111/j.1474-9726.2009.00460.x

Rodrigues, J. P., Mastaglia, F. L., & Thickbroom, G. W. (2009). Rapid slowing of maximal finger movement rate: Fatigue of central motor control? *Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 196*(4), 557-563. doi: 10.1007/s00221-009-1886-2

Roos, M. R., Rice, C. L., & Vandervoort, A. A. (1997). Age-related changes in motor unit function. *Muscle & Nerve, 20*(6), 679-690.

Rotto, D. M., & Kaufman, M. P. (1988). Effect of metabolic products of muscular contraction on discharge of group III and IV afferents. *Journal of Applied Physiology (Bethesda, Md.: 1985), 64*(6), 2306-2313.

Rudolph, K. S., Axe, M. J., & Snyder-Mackler, L. (2000). Dynamic stability after ACL injury: Who can hop? *Knee Surgery, Sports Traumatology, Arthroscopy : Official Journal of the ESSKA, 8*(5), 262-269.

Ruff, R. M., & Parker, S. B. (1993). Gender- and age-specific changes in motor speed and eye-hand coordination in adults: Normative values for the finger tapping and grooved pegboard tests. *Perceptual and Motor Skills, 76*(3 Pt 2), 1219-1230.

Ruiz, P. J., Bernardos, V. S., Bartolome, M., & Torres, A. G. (2007). Capit timed tests quantify age-related motor decline in normal subjects. *Journal of the Neurological Sciences, 260*(1-2), 283-285. doi: 10.1016/j.jns.2007.04.034

Sacco, P., Thickbroom, G. W., Byrnes, M. L., & Mastaglia, F. L. (2000). Changes in corticomotor excitability after fatiguing muscle contractions. *Muscle & Nerve, 23*(12), 1840-1846.

Samii, A., Wassermann, E. M., Ikoma, K., Mercuri, B., George, M. S., O'Fallon, A., . . . Hallett, M. (1996). Decreased postexercise facilitation of motor evoked potentials in patients with chronic fatigue syndrome or depression. *Neurology, 47*(6), 1410-1414.

Seidler, R. D., Noll, D. C., & Thiers, G. (2004). Feedforward and feedback processes in motor control. *NeuroImage, 22*(4), 1775-1783. doi: 10.1016/j.neuroimage.2004.05.003

Shadmehr, R., Smith, M. A., & Krakauer, J. W. (2010). Error correction, sensory prediction, and adaptation in motor control. *Annual Review of Neuroscience, 33*, 89-108. doi: 10.1146/annurev-neuro-060909-153135

Smith, D. O., & Rosenheimer, J. L. (1982). Decreased sprouting and degeneration of nerve terminals of active muscles in aged rats. *Journal of Neurophysiology, 48*(1), 100-109.

Taylor, J. L., Butler, J. E., & Gandevia, S. C. (2000). Changes in muscle afferents, motoneurons and motor drive during muscle fatigue. *European Journal of Applied Physiology, 83*(2-3), 106-115. doi: 10.1007/s004210000269

Taylor, J. L., & Gandevia, S. C. (2008). A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. *Journal of Applied Physiology (Bethesda, Md.: 1985), 104*(2), 542-550. doi: 10.1152/japplphysiol.01053.2007

Taylor, J. L., & Gandevia, S. C. (2008). A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. *Journal of Applied Physiology (Bethesda, Md.: 1985), 104*(2), 542-550. doi: 10.1152/japplphysiol.01053.2007

Taylor, J. L., Todd, G., & Gandevia, S. C. (2006). Evidence for a supraspinal contribution to human muscle fatigue. *Clinical and Experimental Pharmacology & Physiology, 33*(4), 400-405. doi: 10.1111/j.1440-1681.2006.04363.x

Teo, W. P., Rodrigues, J. P., Mastaglia, F. L., & Thickbroom, G. W. (2012a). Breakdown in central motor control can be attenuated by motor practice and neuro-modulation of the primary motor cortex. *Neuroscience,220*, 11-18. doi: 10.1016/j.neuroscience.2012.06.048

Teo, W. P., Rodrigues, J. P., Mastaglia, F. L., & Thickbroom, G. W. (2012b). Changes in corticomotor excitability and inhibition after exercise are influenced by hand dominance and motor demand. *Neuroscience, 210*, 110-117. doi: 10.1016/j.neuroscience.2012.03.021

Teo, W. P., Rodrigues, J. P., Mastaglia, F. L., & Thickbroom, G. W. (2012c). Post-exercise depression in corticomotor excitability after dynamic movement: A general property of fatiguing and non-fatiguing exercise.*Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 216*(1), 41-49. doi: 10.1007/s00221-011-2906-6

Thickbroom, G. W., Byrnes, M. L., Sacco, P., Ghosh, S., Morris, I. T., & Mastaglia, F. L. (2000). The role of the supplementary motor area in externally timed movement: The influence of predictability of movement timing. *Brain Research, 874*(2), 233-241.

Thickbroom, G. W., Phillips, B. A., Morris, I., Byrnes, M. L., Sacco, P., & Mastaglia, F. L. (1999). Differences in functional magnetic resonance imaging of sensorimotor cortex during static and dynamic finger flexion.*Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 126*(3), 431-438.

Wagner, M. J., & Smith, M. A. (2008). Shared internal models for feedforward and feedback control. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience, 28*(42), 10663-10673. doi: 10.1523/JNEUROSCI.5479-07.2008

Ward, N. S. (2006). Compensatory mechanisms in the aging motor system. *Ageing Research Reviews, 5*(3), 239-254. doi: 10.1016/j.arr.2006.04.003

Windhorst, U., Kirmayer, D., Soibelman, F., Misri, A., & Rose, R. (1997). Effects of neurochemically excited group III-IV muscle afferents on motoneuron afterhyperpolarization. *Neuroscience, 76*(3), 915-929.

Wokke, J. H., Jennekens, F. G., van den Oord, C. J., Veldman, H., Smit, L. M., & Leppink, G. J. (1990). Morphological changes in the human end plate with age. *Journal of the Neurological Sciences, 95*(3), 291-310.

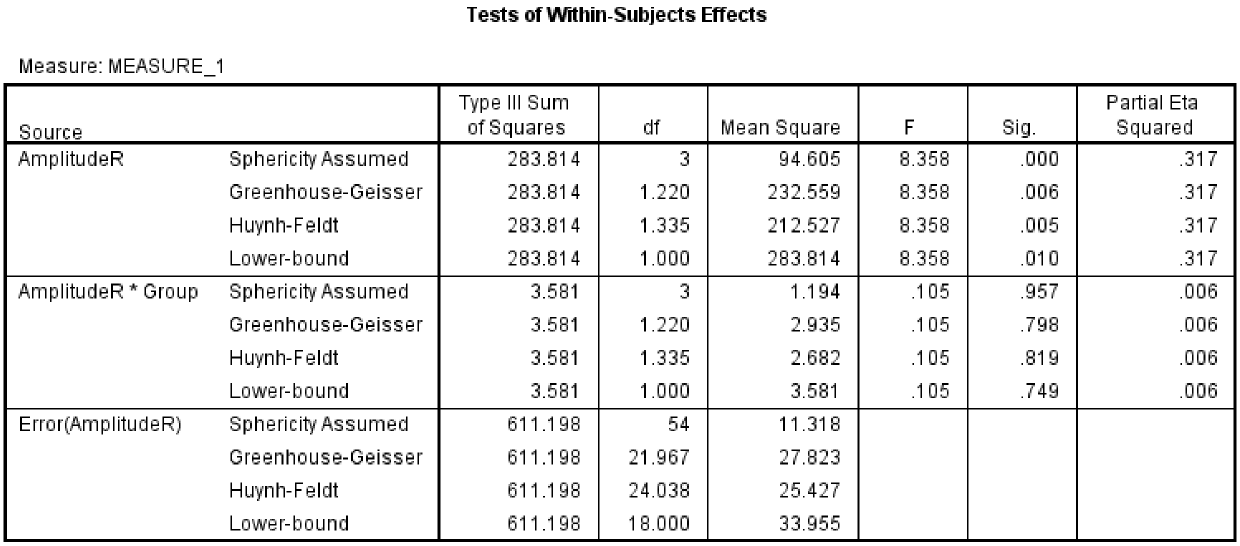
Wu, T., & Hallett, M. (2005). The influence of normal human ageing on automatic movements. *The Journal of Physiology, 562*(Pt 2), 605-615. doi: 10.1113/jphysiol.2004.076042

Zwarts, M. J., Bleijenberg, G., & van Engelen, B. G. (2008). Clinical neurophysiology of fatigue. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology, 119*(1), 2-10. doi: 10.1016/j.clinph.2007.09.126

Appendices

Appendix 1: SPSS Statistical Analyses Tables

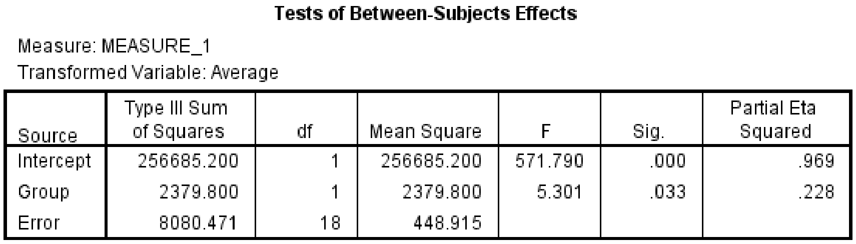
1. Amplitude (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

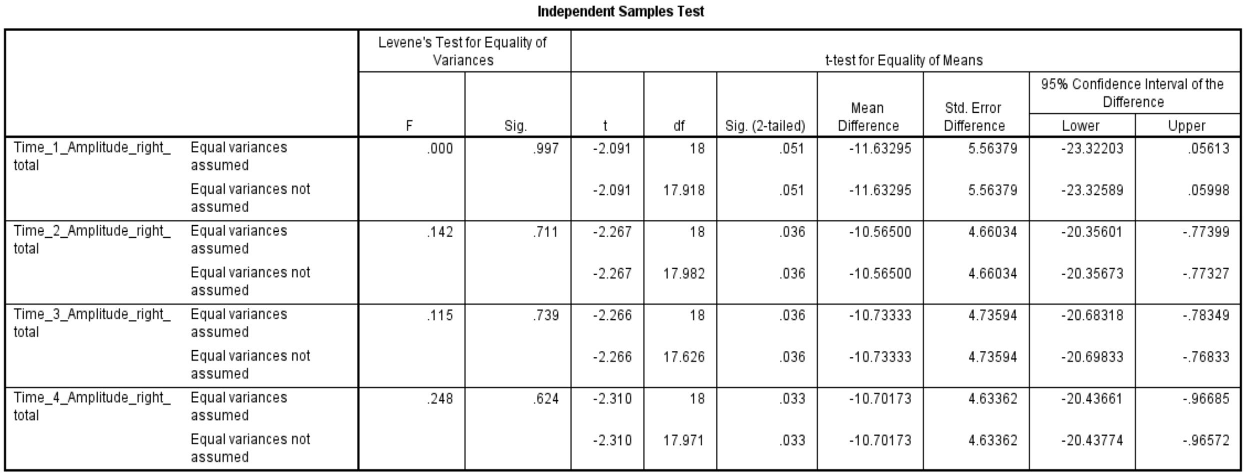
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AmplitudeR	Sphericity Assumed	283.814	3	94.605	8.358	.000	.317
	Greenhouse-Geisser	283.814	1.220	232.559	8.358	.006	.317
	Huynh-Feldt	283.814	1.335	212.527	8.358	.005	.317
	Lower-bound	283.814	1.000	283.814	8.358	.010	.317
AmplitudeR * Group	Sphericity Assumed	3.581	3	1.194	.105	.957	.006
	Greenhouse-Geisser	3.581	1.220	2.935	.105	.798	.006
	Huynh-Feldt	3.581	1.335	2.682	.105	.819	.006
	Lower-bound	3.581	1.000	3.581	.105	.749	.006
Error(AmplitudeR)	Sphericity Assumed	611.198	54	11.318			
	Greenhouse-Geisser	611.198	21.967	27.823			
	Huynh-Feldt	611.198	24.038	25.427			
	Lower-bound	611.198	18.000	33.955			



Tests of Between-Subjects Effects

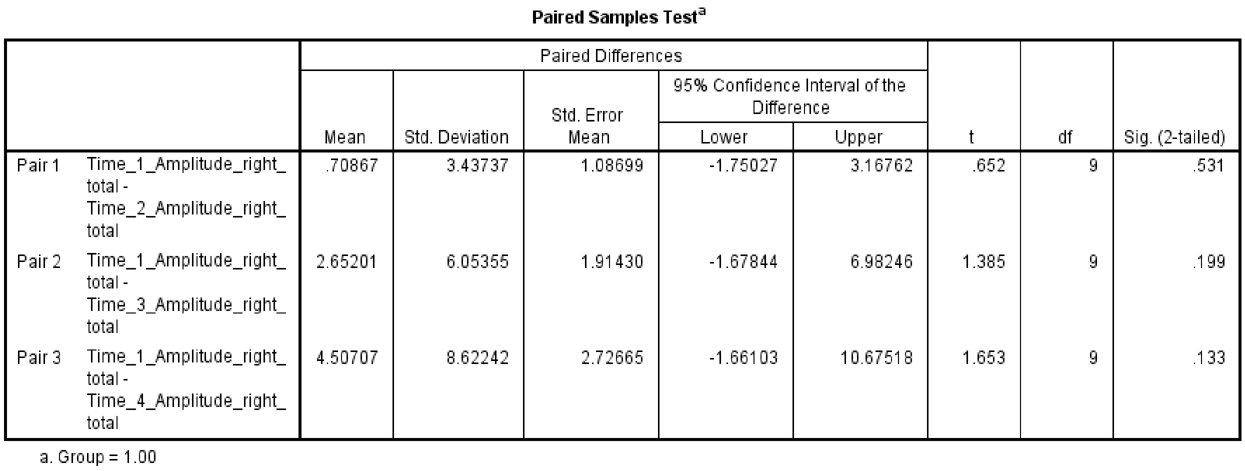
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	256685.200	1	256685.200	571.790	.000	.969
Group	2379.800	1	2379.800	5.301	.033	.228
Error	8080.471	18	448.915			



Independent Samples Test

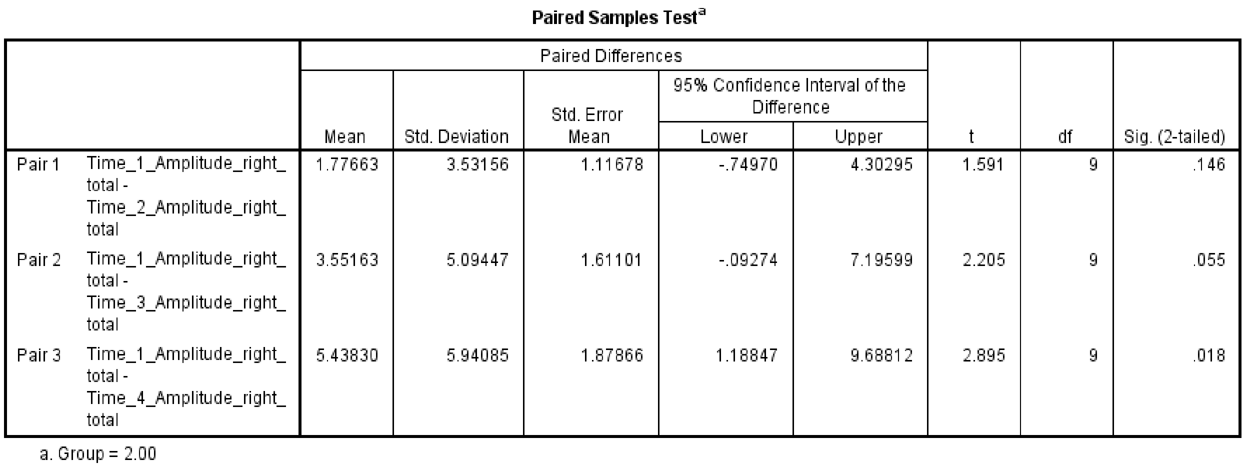
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_Amplitude_right_total	Equal variances assumed	.000	.997	-2.091	18	.051	-11.63295	5.56379	-23.32203	.05613
	Equal variances not assumed			-2.091	17.918	.051	-11.63295	5.56379	-23.32589	.05998
Time_2_Amplitude_right_total	Equal variances assumed	.142	.711	-2.267	18	.036	-10.56500	4.66034	-20.35601	-.77399
	Equal variances not assumed			-2.267	17.982	.036	-10.56500	4.66034	-20.35673	-.77327
Time_3_Amplitude_right_total	Equal variances assumed	.115	.739	-2.266	18	.036	-10.73333	4.73594	-20.68318	-.78349
	Equal variances not assumed			-2.266	17.626	.036	-10.73333	4.73594	-20.69833	-.76833
Time_4_Amplitude_right_total	Equal variances assumed	.248	.624	-2.310	18	.033	-10.70173	4.63362	-20.43661	-.96685
	Equal variances not assumed			-2.310	17.971	.033	-10.70173	4.63362	-20.43774	-.96572



Paired Samples Test^a

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_Amplitude_right_total - Time_2_Amplitude_right_total	.70867	3.43737	1.08699	-1.75027	3.16762	.652	9	.531
Pair 2	Time_1_Amplitude_right_total - Time_3_Amplitude_right_total	2.65201	6.05355	1.91430	-1.67844	6.98246	1.385	9	.199
Pair 3	Time_1_Amplitude_right_total - Time_4_Amplitude_right_total	4.50707	8.62242	2.72665	-1.66103	10.67518	1.653	9	.133

a. Group = 1.00

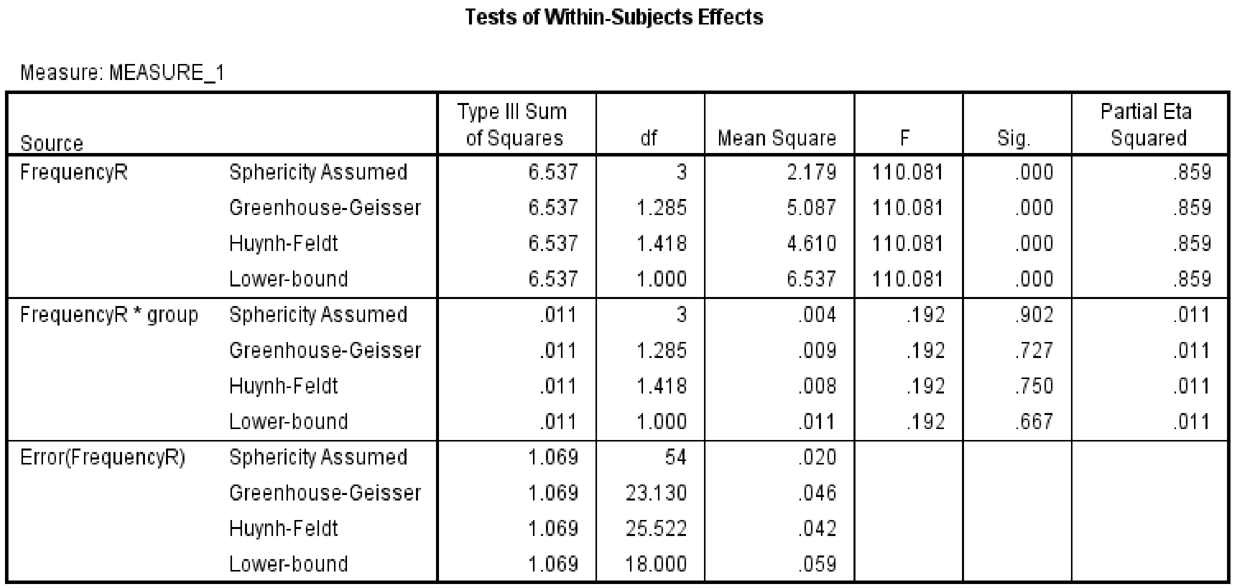


Paired Samples Test^a

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_Amplitude_right_total - Time_2_Amplitude_right_total	1.77663	3.53156	1.11678	-.74970	4.30295	1.591	9	.146
Pair 2	Time_1_Amplitude_right_total - Time_3_Amplitude_right_total	3.55163	5.09447	1.61101	-.09274	7.19599	2.205	9	.055
Pair 3	Time_1_Amplitude_right_total - Time_4_Amplitude_right_total	5.43830	5.94085	1.87866	1.18847	9.68812	2.895	9	.018

a. Group = 2.00

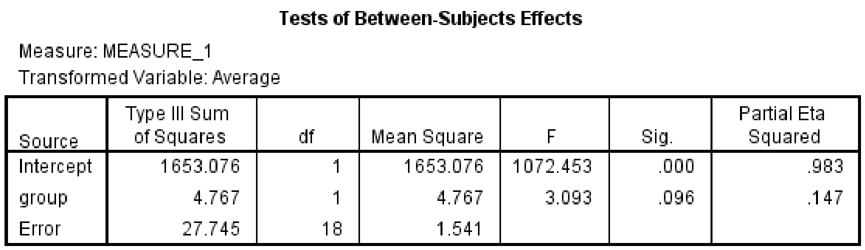
2. Frequency (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

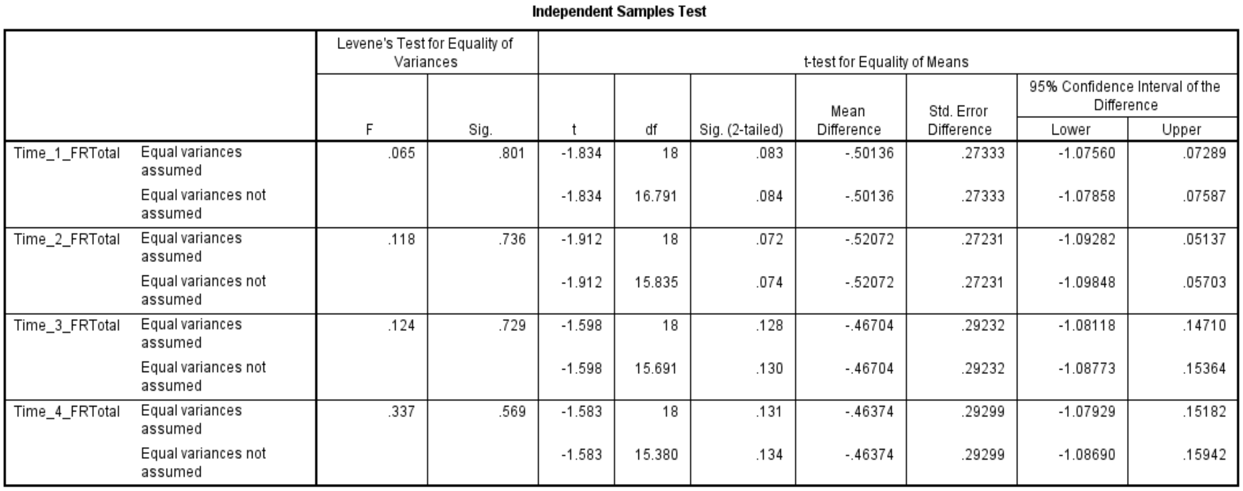
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
FrequencyR	Sphericity Assumed	6.537	3	2.179	110.081	.000	.859
	Greenhouse-Geisser	6.537	1.285	5.087	110.081	.000	.859
	Huynh-Feldt	6.537	1.418	4.610	110.081	.000	.859
	Lower-bound	6.537	1.000	6.537	110.081	.000	.859
FrequencyR * group	Sphericity Assumed	.011	3	.004	.192	.902	.011
	Greenhouse-Geisser	.011	1.285	.009	.192	.727	.011
	Huynh-Feldt	.011	1.418	.008	.192	.750	.011
	Lower-bound	.011	1.000	.011	.192	.667	.011
Error(FrequencyR)	Sphericity Assumed	1.069	54	.020			
	Greenhouse-Geisser	1.069	23.130	.046			
	Huynh-Feldt	1.069	25.522	.042			
	Lower-bound	1.069	18.000	.059			



Tests of Between-Subjects Effects

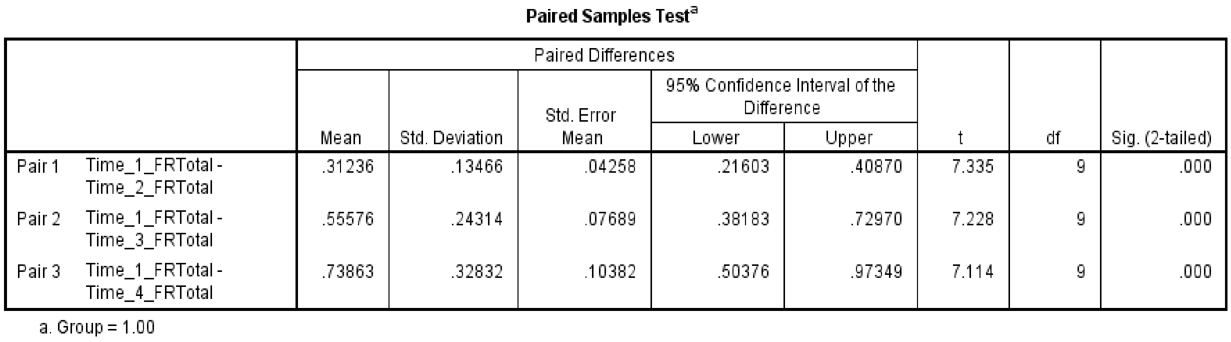
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1653.076	1	1653.076	1072.453	.000	.983
group	4.767	1	4.767	3.093	.096	.147
Error	27.745	18	1.541			



Independent Samples Test

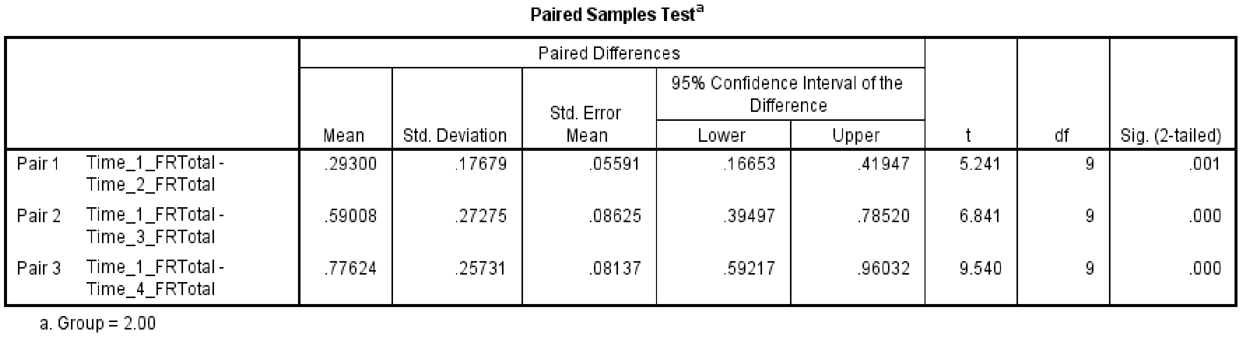
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_FRTotal	Equal variances assumed	.065	.801	-1.834	18	.083	-.50136	.27333	-1.07560	.07289
	Equal variances not assumed			-1.834	16.791	.084	-.50136	.27333	-1.07858	.07587
Time_2_FRTotal	Equal variances assumed	.118	.736	-1.912	18	.072	-.52072	.27231	-1.09282	.05137
	Equal variances not assumed			-1.912	15.835	.074	-.52072	.27231	-1.09848	.05703
Time_3_FRTotal	Equal variances assumed	.124	.729	-1.598	18	.128	-.46704	.29232	-1.08118	.14710
	Equal variances not assumed			-1.598	15.691	.130	-.46704	.29232	-1.08773	.15364
Time_4_FRTotal	Equal variances assumed	.337	.569	-1.583	18	.131	-.46374	.29299	-1.07929	.15182
	Equal variances not assumed			-1.583	15.380	.134	-.46374	.29299	-1.08690	.15942



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_FRTotal - Time_2_FRTotal	.31236	.13466	.04258	.21603	.40870	7.335	9	.000
Pair 2	Time_1_FRTotal - Time_3_FRTotal	.55576	.24314	.07689	.38183	.72970	7.228	9	.000
Pair 3	Time_1_FRTotal - Time_4_FRTotal	.73863	.32832	.10382	.50376	.97349	7.114	9	.000

a. Group = 1.00

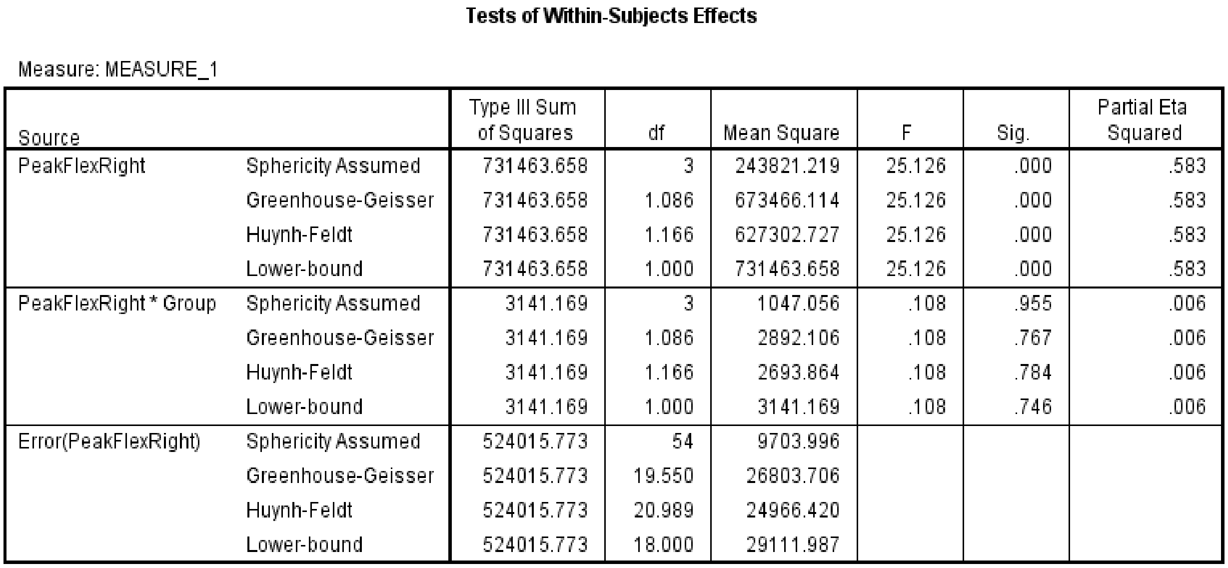


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_FRTotal - Time_2_FRTotal	.29300	.17679	.05591	.16653	.41947	5.241	9	.001
Pair 2	Time_1_FRTotal - Time_3_FRTotal	.59008	.27275	.08625	.39497	.78520	6.841	9	.000
Pair 3	Time_1_FRTotal - Time_4_FRTotal	.77624	.25731	.08137	.59217	.96032	9.540	9	.000

a. Group = 2.00

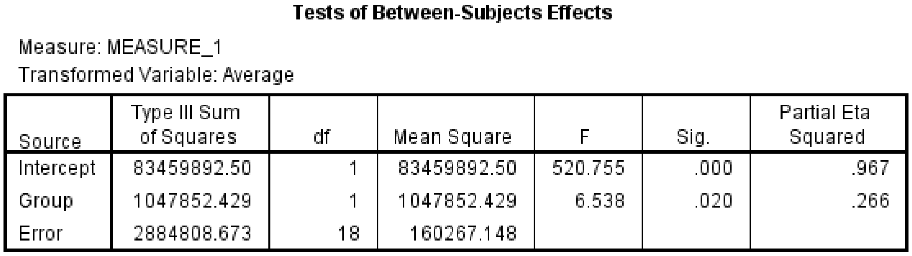
3. Peak Velocity Flexor (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

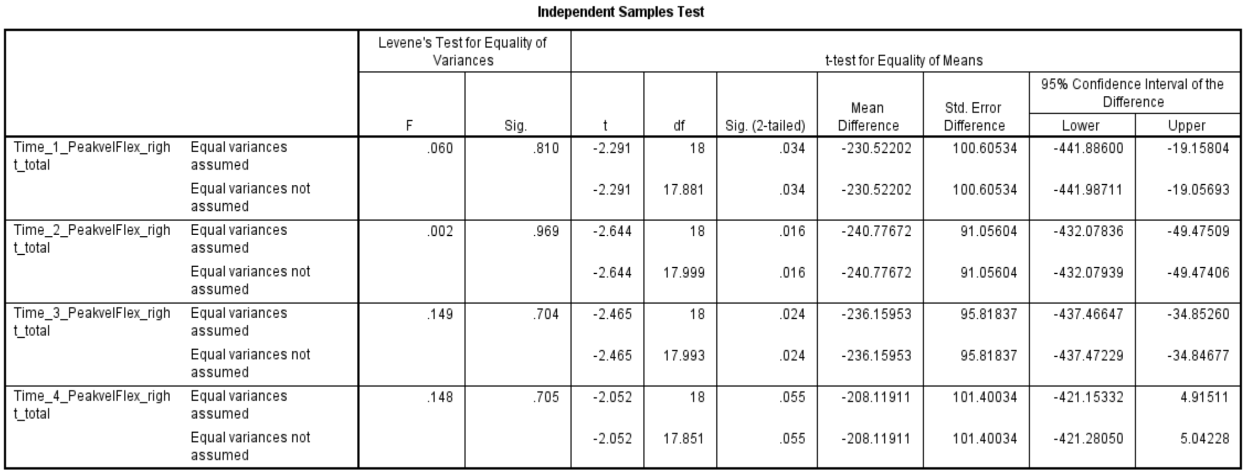
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PeakFlexRight	Sphericity Assumed	731463.658	3	243821.219	25.126	.000	.583
	Greenhouse-Geisser	731463.658	1.086	673466.114	25.126	.000	.583
	Huynh-Feldt	731463.658	1.166	627302.727	25.126	.000	.583
	Lower-bound	731463.658	1.000	731463.658	25.126	.000	.583
PeakFlexRight * Group	Sphericity Assumed	3141.169	3	1047.056	.108	.955	.006
	Greenhouse-Geisser	3141.169	1.086	2892.106	.108	.767	.006
	Huynh-Feldt	3141.169	1.166	2693.864	.108	.784	.006
	Lower-bound	3141.169	1.000	3141.169	.108	.746	.006
Error(PeakFlexRight)	Sphericity Assumed	524015.773	54	9703.996			
	Greenhouse-Geisser	524015.773	19.550	26803.706			
	Huynh-Feldt	524015.773	20.989	24966.420			
	Lower-bound	524015.773	18.000	29111.987			



Tests of Between-Subjects Effects

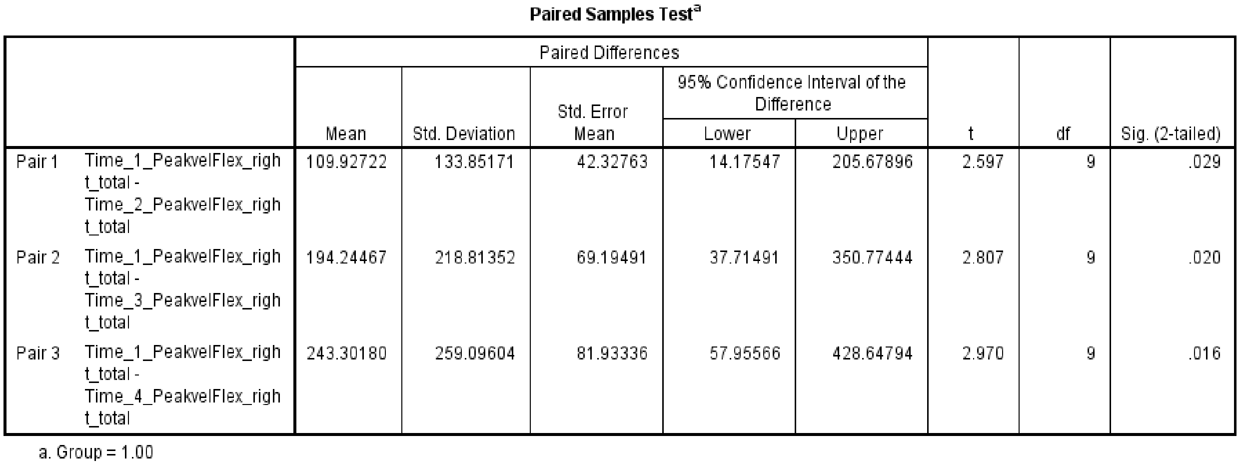
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	83459892.50	1	83459892.50	520.755	.000	.967
Group	1047852.429	1	1047852.429	6.538	.020	.266
Error	2884808.673	18	160267.148			



Independent Samples Test

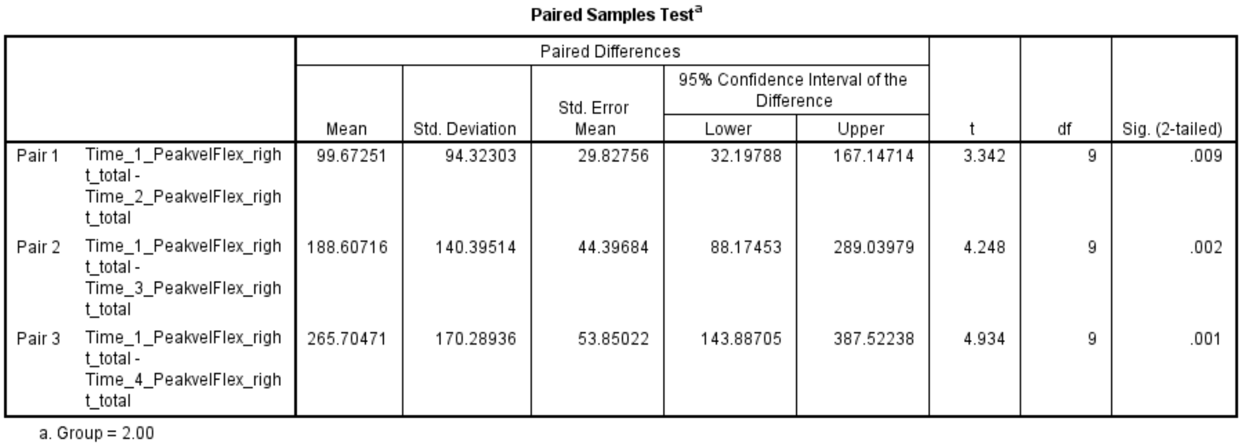
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_PeakvelFlex_right_total	Equal variances assumed	.060	.810	-2.291	18	.034	-230.52202	100.60534	-441.88600	-19.15804
	Equal variances not assumed			-2.291	17.881	.034	-230.52202	100.60534	-441.98711	-19.05693
Time_2_PeakvelFlex_right_total	Equal variances assumed	.002	.969	-2.644	18	.016	-240.77672	91.05604	-432.07836	-49.47509
	Equal variances not assumed			-2.644	17.999	.016	-240.77672	91.05604	-432.07939	-49.47406
Time_3_PeakvelFlex_right_total	Equal variances assumed	.149	.704	-2.465	18	.024	-236.15953	95.81837	-437.46647	-34.85260
	Equal variances not assumed			-2.465	17.993	.024	-236.15953	95.81837	-437.47229	-34.84677
Time_4_PeakvelFlex_right_total	Equal variances assumed	.148	.705	-2.052	18	.055	-208.11911	101.40034	-421.15332	4.91511
	Equal variances not assumed			-2.052	17.851	.055	-208.11911	101.40034	-421.28050	5.04228



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Time_1_PeakvelFlex_right_total - Time_2_PeakvelFlex_right_total	109.92722	133.85171	42.32763	14.17547	205.67896	2.597	9	.029
Pair 2	Time_1_PeakvelFlex_right_total - Time_3_PeakvelFlex_right_total	194.24467	218.81352	69.19491	37.71491	350.77444	2.807	9	.020
Pair 3	Time_1_PeakvelFlex_right_total - Time_4_PeakvelFlex_right_total	243.30180	259.09604	81.93336	57.95566	428.64794	2.970	9	.016

a. Group = 1.00

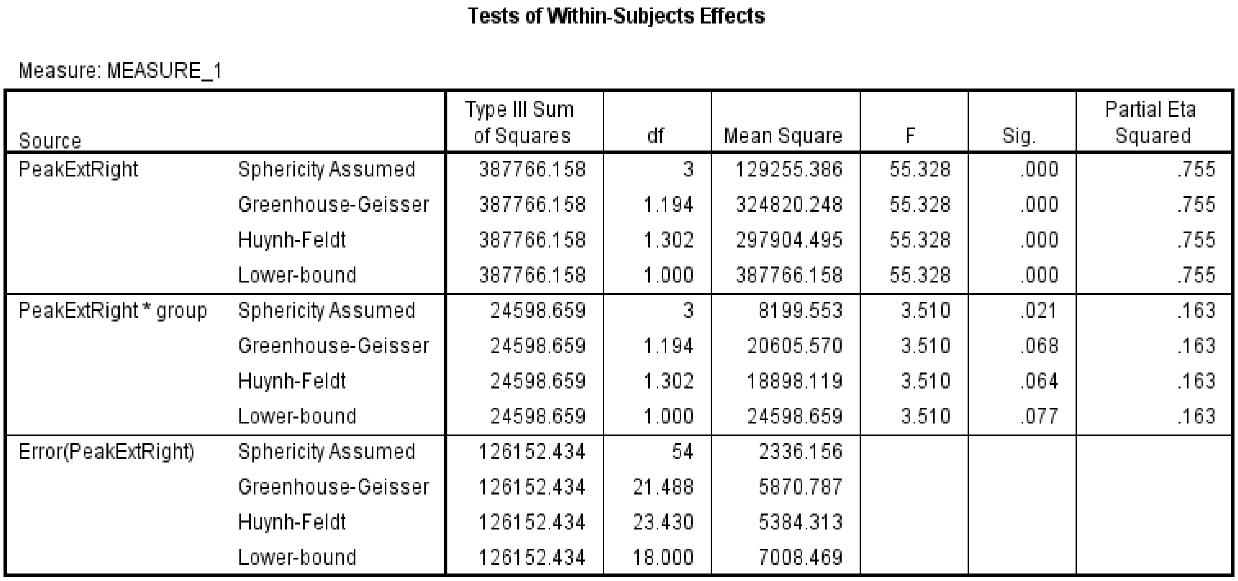


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Time_1_PeakvelFlex_right_total - Time_2_PeakvelFlex_right_total	99.67251	94.32303	29.82756	32.19788	167.14714	3.342	9	.009
Pair 2	Time_1_PeakvelFlex_right_total - Time_3_PeakvelFlex_right_total	188.60716	140.39514	44.39684	88.17453	289.03979	4.248	9	.002
Pair 3	Time_1_PeakvelFlex_right_total - Time_4_PeakvelFlex_right_total	265.70471	170.28936	53.85022	143.88705	387.52238	4.934	9	.001

a. Group = 2.00

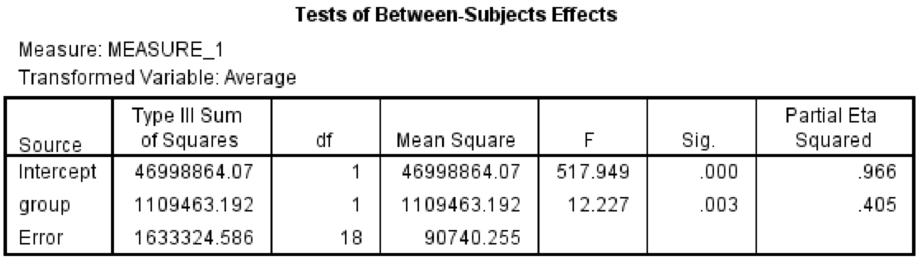
4. Peak Velocity Extensor (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

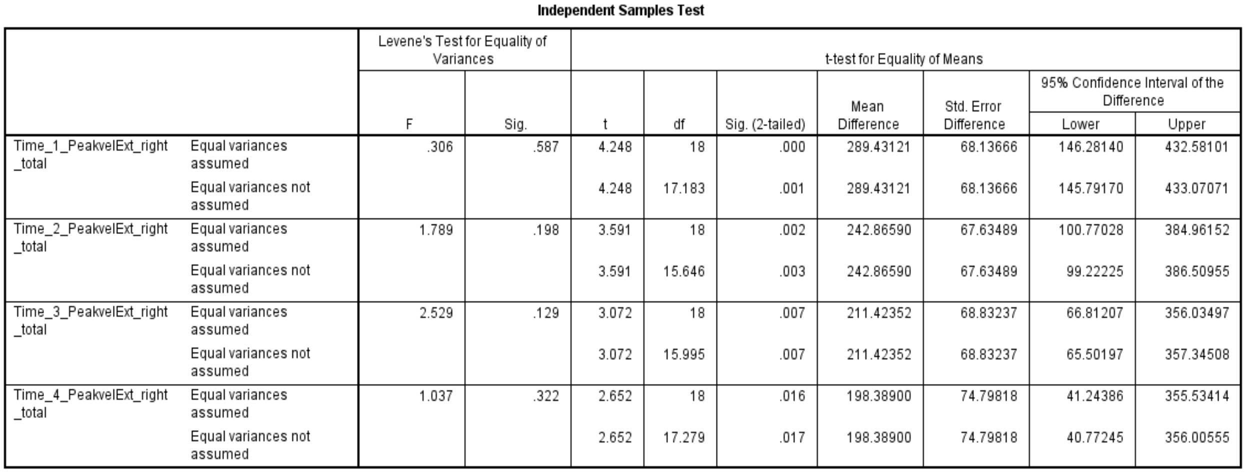
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PeakExtRight	Sphericity Assumed	387766.158	3	129255.386	55.328	.000	.755
	Greenhouse-Geisser	387766.158	1.194	324820.248	55.328	.000	.755
	Huynh-Feldt	387766.158	1.302	297904.495	55.328	.000	.755
	Lower-bound	387766.158	1.000	387766.158	55.328	.000	.755
PeakExtRight * group	Sphericity Assumed	24598.659	3	8199.553	3.510	.021	.163
	Greenhouse-Geisser	24598.659	1.194	20605.570	3.510	.068	.163
	Huynh-Feldt	24598.659	1.302	18898.119	3.510	.064	.163
	Lower-bound	24598.659	1.000	24598.659	3.510	.077	.163
Error(PeakExtRight)	Sphericity Assumed	126152.434	54	2336.156			
	Greenhouse-Geisser	126152.434	21.488	5870.787			
	Huynh-Feldt	126152.434	23.430	5384.313			
	Lower-bound	126152.434	18.000	7008.469			



Tests of Between-Subjects Effects

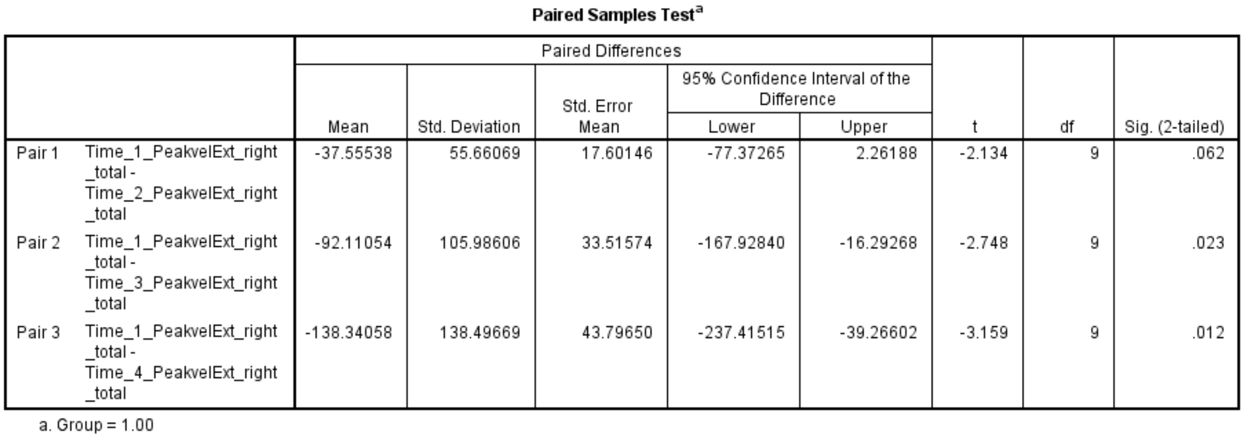
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	46998864.07	1	46998864.07	517.949	.000	.966
group	1109463.192	1	1109463.192	12.227	.003	.405
Error	1633324.586	18	90740.255			



Independent Samples Test

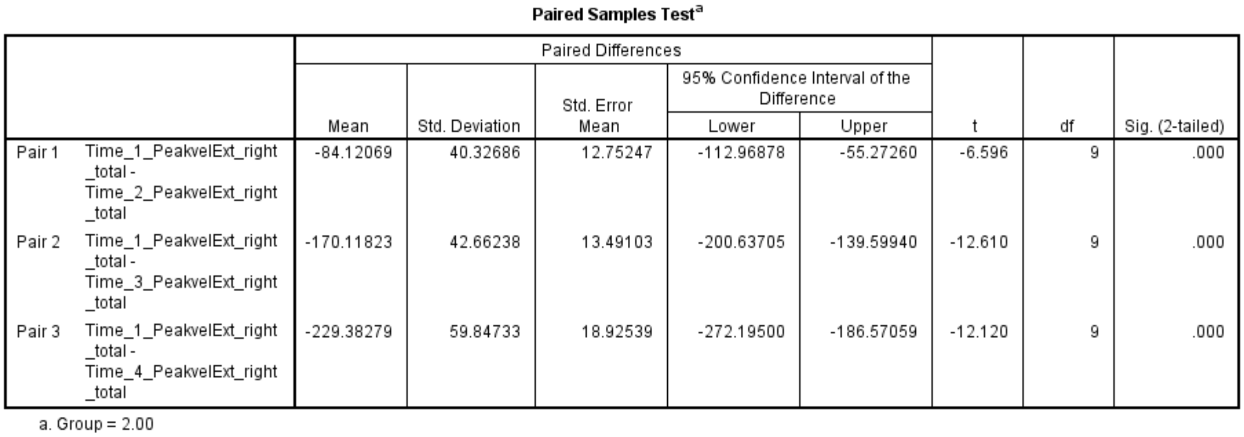
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_PeakvelExt_right_total	Equal variances assumed	.306	.587	4.248	18	.000	289.43121	68.13666	146.28140	432.58101
	Equal variances not assumed			4.248	17.183	.001	289.43121	68.13666	145.79170	433.07071
Time_2_PeakvelExt_right_total	Equal variances assumed	1.789	.198	3.591	18	.002	242.86590	67.63489	100.77028	384.96152
	Equal variances not assumed			3.591	15.646	.003	242.86590	67.63489	99.22225	386.50955
Time_3_PeakvelExt_right_total	Equal variances assumed	2.529	.129	3.072	18	.007	211.42352	68.83237	66.81207	356.03497
	Equal variances not assumed			3.072	15.995	.007	211.42352	68.83237	65.50197	357.34508
Time_4_PeakvelExt_right_total	Equal variances assumed	1.037	.322	2.652	18	.016	198.38900	74.79818	41.24386	355.53414
	Equal variances not assumed			2.652	17.279	.017	198.38900	74.79818	40.77245	356.00555



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_PeakvelExt_right_total - Time_2_PeakvelExt_right_total	-37.55538	55.66069	17.60146	-77.37265	2.26188	-2.134	9	.062
Pair 2	Time_1_PeakvelExt_right_total - Time_3_PeakvelExt_right_total	-92.11054	105.98606	33.51574	-167.92840	-16.29268	-2.748	9	.023
Pair 3	Time_1_PeakvelExt_right_total - Time_4_PeakvelExt_right_total	-138.34058	138.49669	43.79650	-237.41515	-39.26602	-3.159	9	.012

a. Group = 1.00

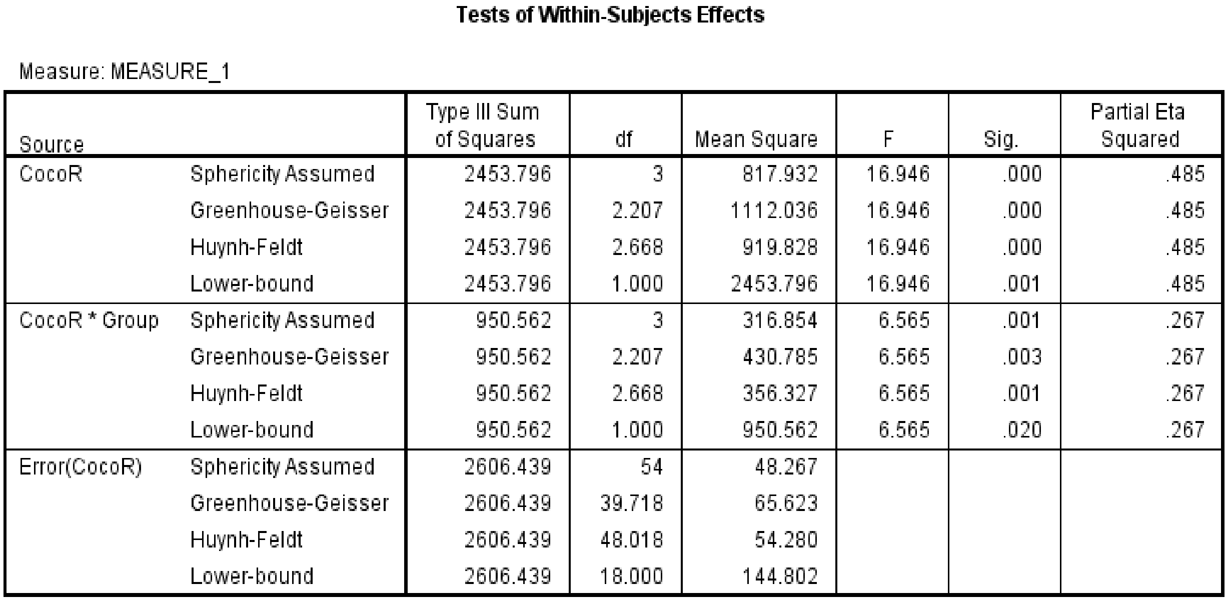


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_PeakvelExt_right_total - Time_2_PeakvelExt_right_total	-84.12069	40.32686	12.75247	-112.96878	-55.27260	-6.596	9	.000
Pair 2	Time_1_PeakvelExt_right_total - Time_3_PeakvelExt_right_total	-170.11823	42.66238	13.49103	-200.63705	-139.59940	-12.610	9	.000
Pair 3	Time_1_PeakvelExt_right_total - Time_4_PeakvelExt_right_total	-229.38279	59.84733	18.92539	-272.19500	-186.57059	-12.120	9	.000

a. Group = 2.00

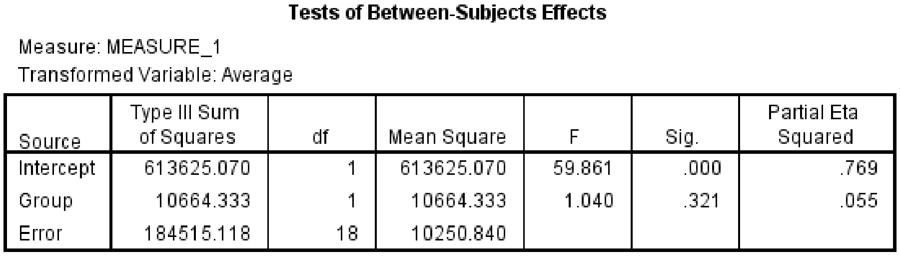
5. Co-contraction (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

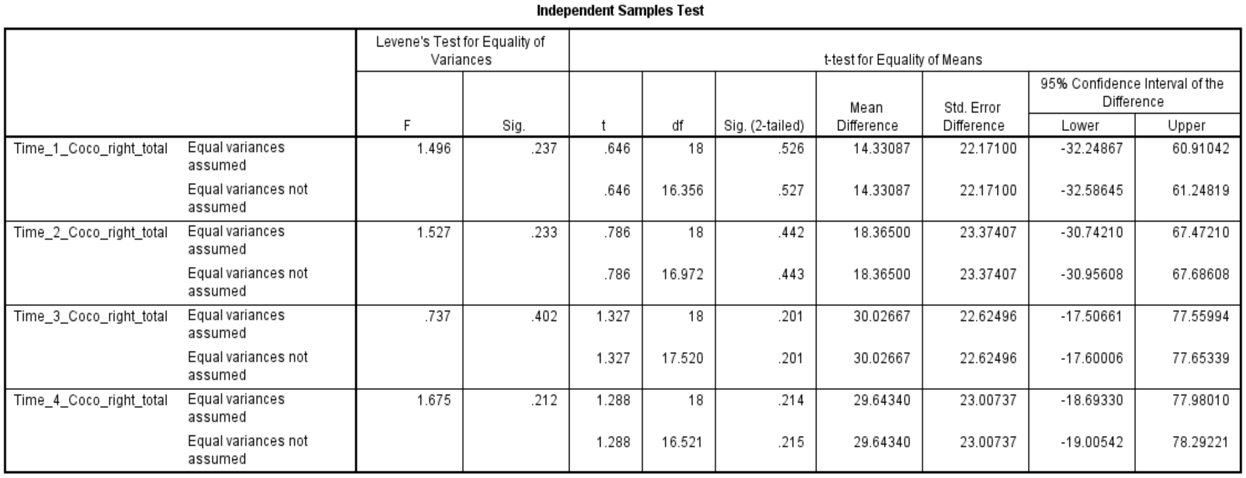
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
CocoR	Sphericity Assumed	2453.796	3	817.932	16.946	.000	.485
	Greenhouse-Geisser	2453.796	2.207	1112.036	16.946	.000	.485
	Huynh-Feldt	2453.796	2.668	919.828	16.946	.000	.485
	Lower-bound	2453.796	1.000	2453.796	16.946	.001	.485
CocoR * Group	Sphericity Assumed	950.562	3	316.854	6.565	.001	.267
	Greenhouse-Geisser	950.562	2.207	430.785	6.565	.003	.267
	Huynh-Feldt	950.562	2.668	356.327	6.565	.001	.267
	Lower-bound	950.562	1.000	950.562	6.565	.020	.267
Error(CocoR)	Sphericity Assumed	2606.439	54	48.267			
	Greenhouse-Geisser	2606.439	39.718	65.623			
	Huynh-Feldt	2606.439	48.018	54.280			
	Lower-bound	2606.439	18.000	144.802			



Tests of Between-Subjects Effects

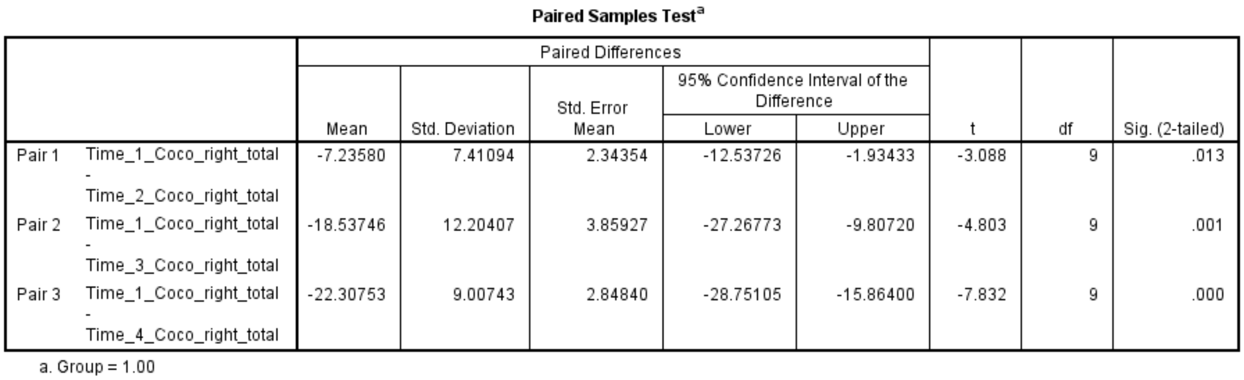
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	613625.070	1	613625.070	59.861	.000	.769
Group	10664.333	1	10664.333	1.040	.321	.055
Error	184515.118	18	10250.840			



Independent Samples Test

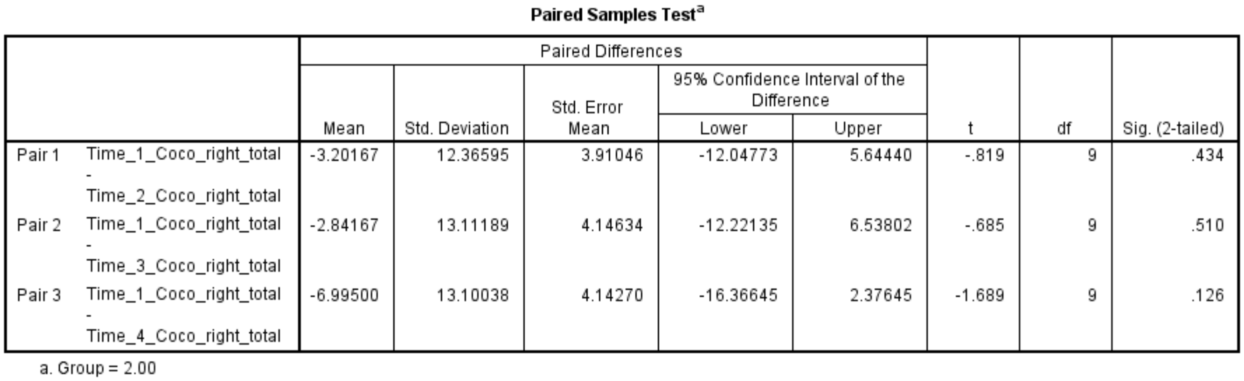
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_Coco_right_total	Equal variances assumed	1.496	.237	.646	18	.526	14.33087	22.17100	-32.24867	60.91042
	Equal variances not assumed			.646	16.356	.527	14.33087	22.17100	-32.58645	61.24819
Time_2_Coco_right_total	Equal variances assumed	1.527	.233	.786	18	.442	18.36500	23.37407	-30.74210	67.47210
	Equal variances not assumed			.786	16.972	.443	18.36500	23.37407	-30.95608	67.68608
Time_3_Coco_right_total	Equal variances assumed	.737	.402	1.327	18	.201	30.02667	22.62496	-17.50661	77.55994
	Equal variances not assumed			1.327	17.520	.201	30.02667	22.62496	-17.60006	77.65339
Time_4_Coco_right_total	Equal variances assumed	1.675	.212	1.288	18	.214	29.64340	23.00737	-18.69330	77.98010
	Equal variances not assumed			1.288	16.521	.215	29.64340	23.00737	-19.00542	78.29221



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Time_1_Coco_right_total - Time_2_Coco_right_total	-7.23580	7.41094	2.34354	-12.53726	-1.93433	-3.088	9	.013
Pair 2	Time_1_Coco_right_total - Time_3_Coco_right_total	-18.53746	12.20407	3.85927	-27.26773	-9.80720	-4.803	9	.001
Pair 3	Time_1_Coco_right_total - Time_4_Coco_right_total	-22.30753	9.00743	2.84840	-28.75105	-15.86400	-7.832	9	.000

a. Group = 1.00

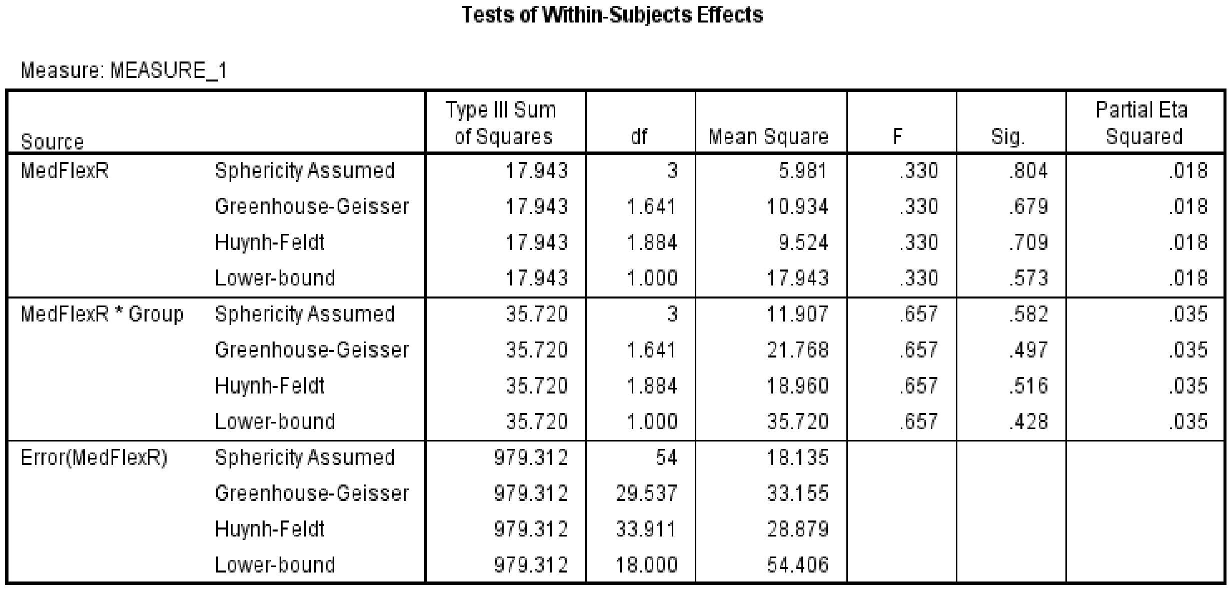


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Time_1_Coco_right_total - Time_2_Coco_right_total	-3.20167	12.36595	3.91046	-12.04773	5.64440	-.819	9	.434
Pair 2	Time_1_Coco_right_total - Time_3_Coco_right_total	-2.84167	13.11189	4.14634	-12.22135	6.53802	-.685	9	.510
Pair 3	Time_1_Coco_right_total - Time_4_Coco_right_total	-6.99500	13.10038	4.14270	-16.36645	2.37645	-1.689	9	.126

a. Group = 2.00

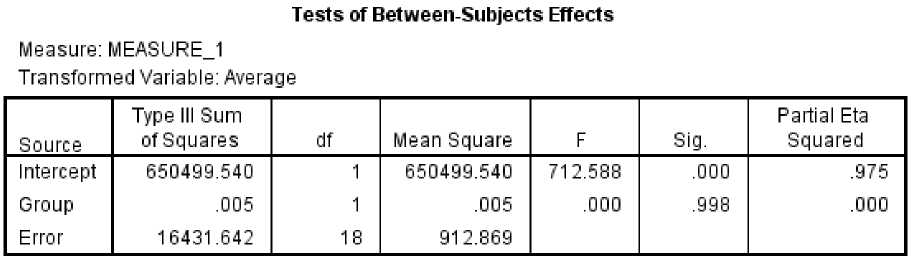
6. Median Frequency Flexor (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

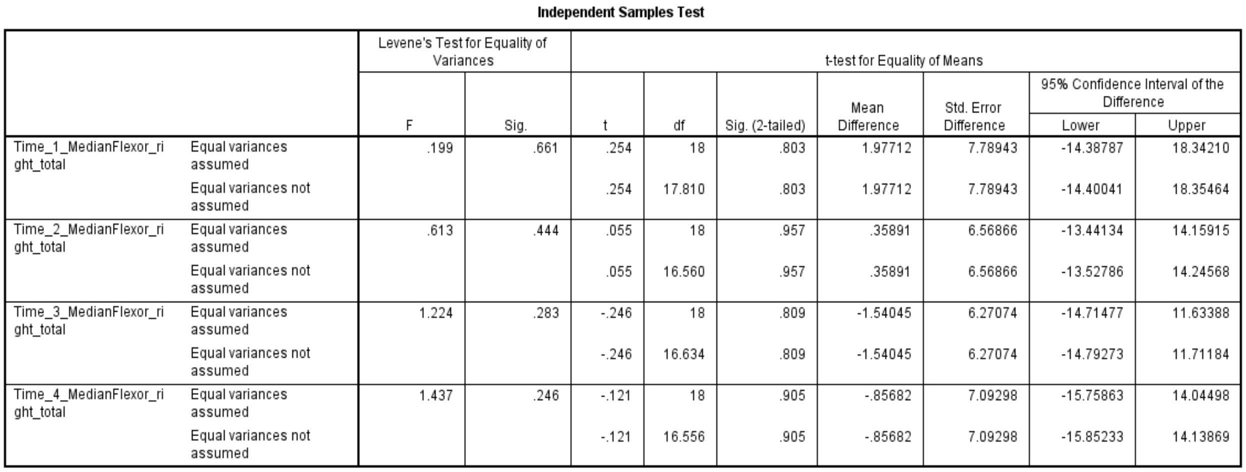
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MedFlexR	Sphericity Assumed	17.943	3	5.981	.330	.804	.018
	Greenhouse-Geisser	17.943	1.641	10.934	.330	.679	.018
	Huynh-Feldt	17.943	1.884	9.524	.330	.709	.018
	Lower-bound	17.943	1.000	17.943	.330	.573	.018
MedFlexR * Group	Sphericity Assumed	35.720	3	11.907	.657	.582	.035
	Greenhouse-Geisser	35.720	1.641	21.768	.657	.497	.035
	Huynh-Feldt	35.720	1.884	18.960	.657	.516	.035
	Lower-bound	35.720	1.000	35.720	.657	.428	.035
Error(MedFlexR)	Sphericity Assumed	979.312	54	18.135			
	Greenhouse-Geisser	979.312	29.537	33.155			
	Huynh-Feldt	979.312	33.911	28.879			
	Lower-bound	979.312	18.000	54.406			



Tests of Between-Subjects Effects

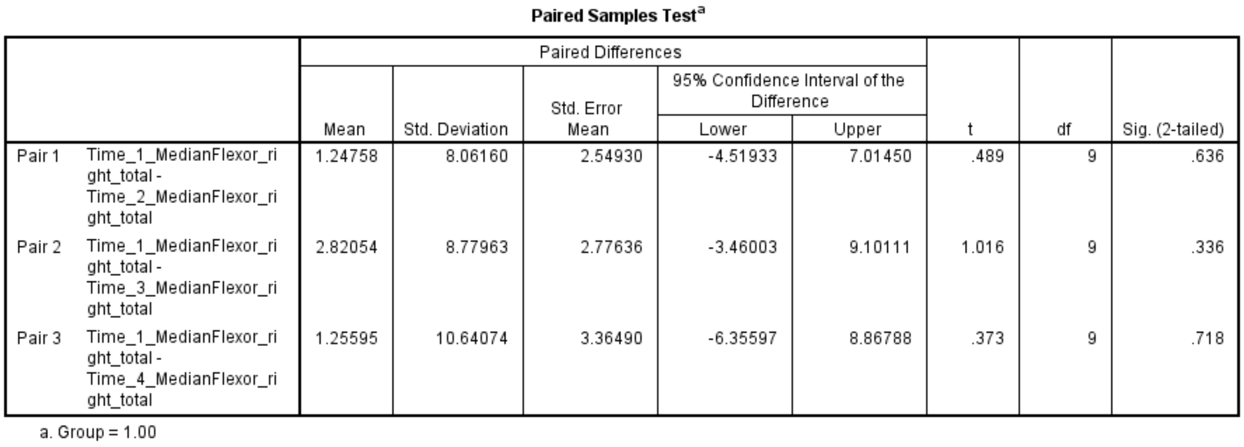
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	650499.540	1	650499.540	712.588	.000	.975
Group	.005	1	.005	.000	.998	.000
Error	16431.642	18	912.869			



Independent Samples Test

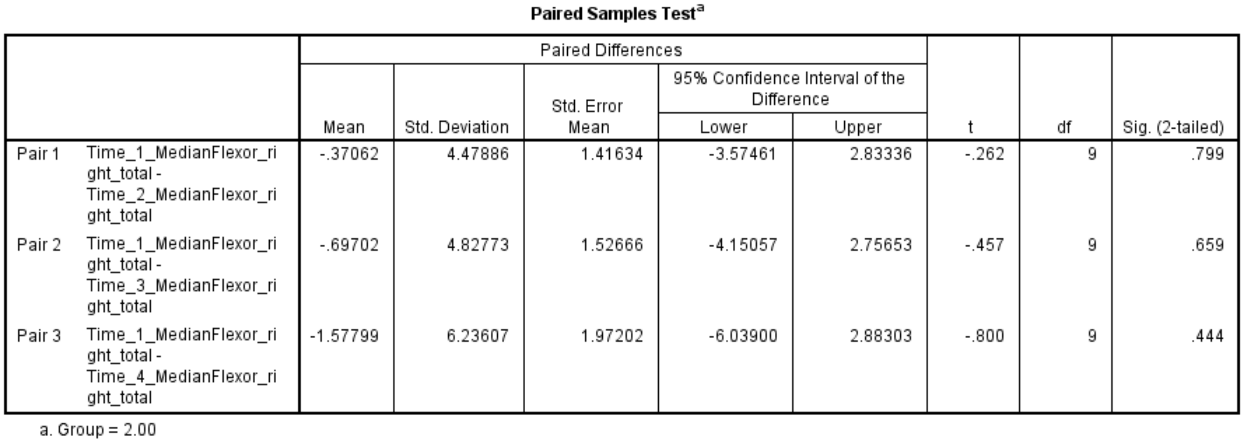
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_MedianFlexor_right_total	Equal variances assumed	.199	.661	.254	18	.803	1.97712	7.78943	-14.38787	18.34210
	Equal variances not assumed			.254	17.810	.803	1.97712	7.78943	-14.40041	18.35464
Time_2_MedianFlexor_right_total	Equal variances assumed	.613	.444	.055	18	.957	.35891	6.56866	-13.44134	14.15915
	Equal variances not assumed			.055	16.560	.957	.35891	6.56866	-13.52786	14.24568
Time_3_MedianFlexor_right_total	Equal variances assumed	1.224	.283	-.246	18	.809	-1.54045	6.27074	-14.71477	11.63388
	Equal variances not assumed			-.246	16.634	.809	-1.54045	6.27074	-14.79273	11.71184
Time_4_MedianFlexor_right_total	Equal variances assumed	1.437	.246	-.121	18	.905	-.85682	7.09298	-15.75863	14.04498
	Equal variances not assumed			-.121	16.556	.905	-.85682	7.09298	-15.85233	14.13869



Paired Samples Test^{a}

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianFlexor_right_total - Time_2_MedianFlexor_right_total	1.24758	8.06160	2.54930	-4.51933	7.01450	.489	9	.636
Pair 2	Time_1_MedianFlexor_right_total - Time_3_MedianFlexor_right_total	2.82054	8.77963	2.77636	-3.46003	9.10111	1.016	9	.336
Pair 3	Time_1_MedianFlexor_right_total - Time_4_MedianFlexor_right_total	1.25595	10.64074	3.36490	-6.35597	8.86788	.373	9	.718

a. Group = 1.00

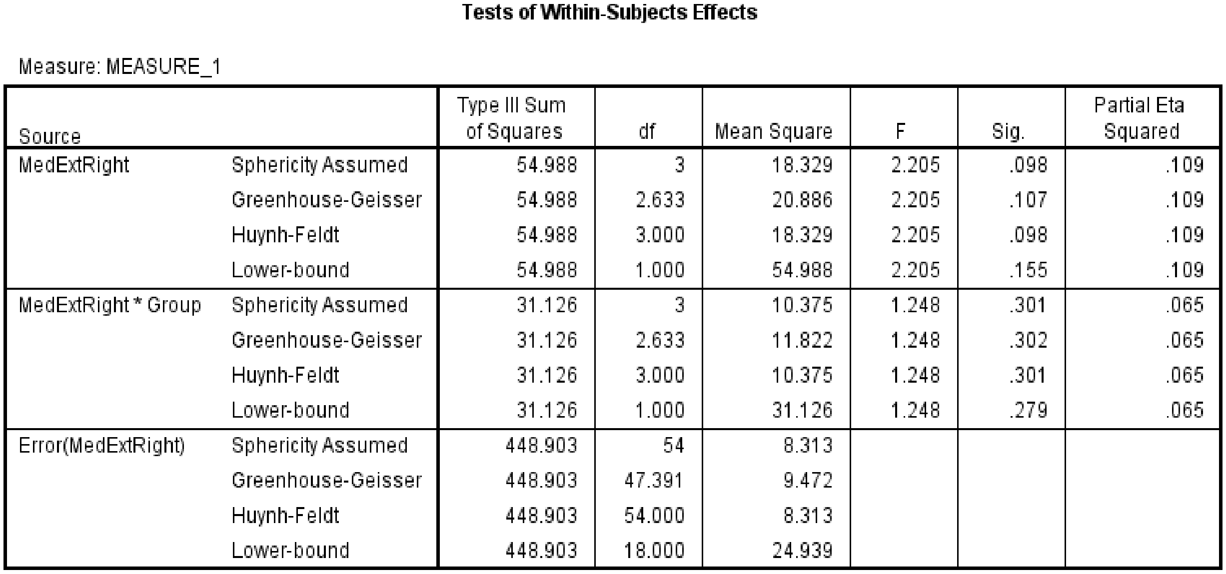


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianFlexor_right_total - Time_2_MedianFlexor_right_total	-.37062	4.47886	1.41634	-3.57461	2.83336	-.262	9	.799
Pair 2	Time_1_MedianFlexor_right_total - Time_3_MedianFlexor_right_total	-.69702	4.82773	1.52666	-4.15057	2.75653	-.457	9	.659
Pair 3	Time_1_MedianFlexor_right_total - Time_4_MedianFlexor_right_total	-1.57799	6.23607	1.97202	-6.03900	2.88303	-.800	9	.444

a. Group = 2.00

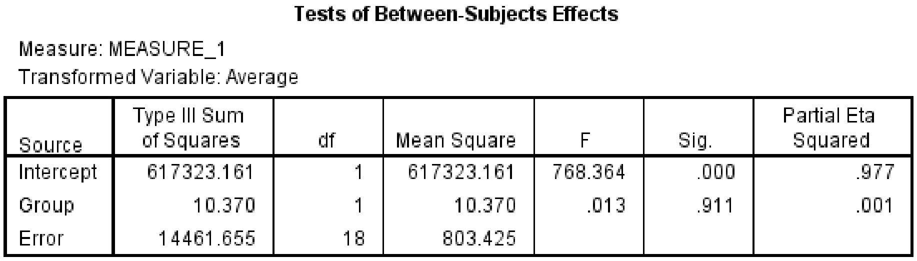
7. Median Frequency Extensor (Dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

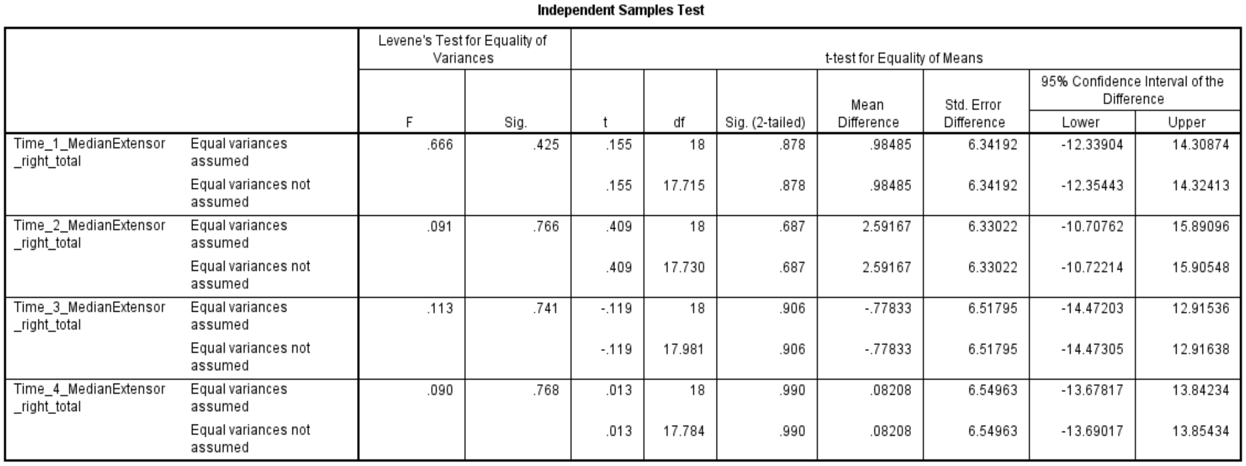
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MedExtRight	Sphericity Assumed	54.988	3	18.329	2.205	.098	.109
	Greenhouse-Geisser	54.988	2.633	20.886	2.205	.107	.109
	Huynh-Feldt	54.988	3.000	18.329	2.205	.098	.109
	Lower-bound	54.988	1.000	54.988	2.205	.155	.109
MedExtRight * Group	Sphericity Assumed	31.126	3	10.375	1.248	.301	.065
	Greenhouse-Geisser	31.126	2.633	11.822	1.248	.302	.065
	Huynh-Feldt	31.126	3.000	10.375	1.248	.301	.065
	Lower-bound	31.126	1.000	31.126	1.248	.279	.065
Error(MedExtRight)	Sphericity Assumed	448.903	54	8.313			
	Greenhouse-Geisser	448.903	47.391	9.472			
	Huynh-Feldt	448.903	54.000	8.313			
	Lower-bound	448.903	18.000	24.939			



Tests of Between-Subjects Effects

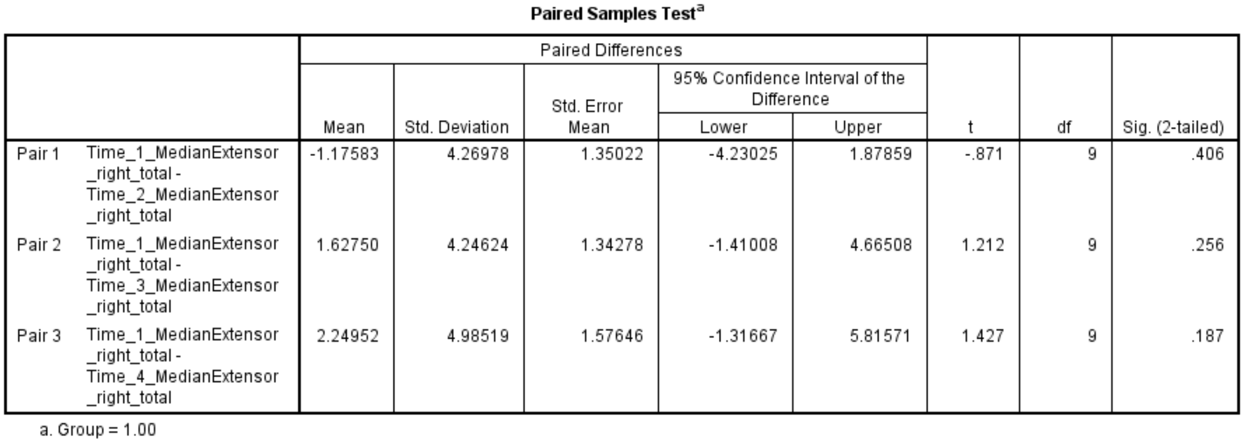
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	617323.161	1	617323.161	768.364	.000	.977
Group	10.370	1	10.370	.013	.911	.001
Error	14461.655	18	803.425			



Independent Samples Test

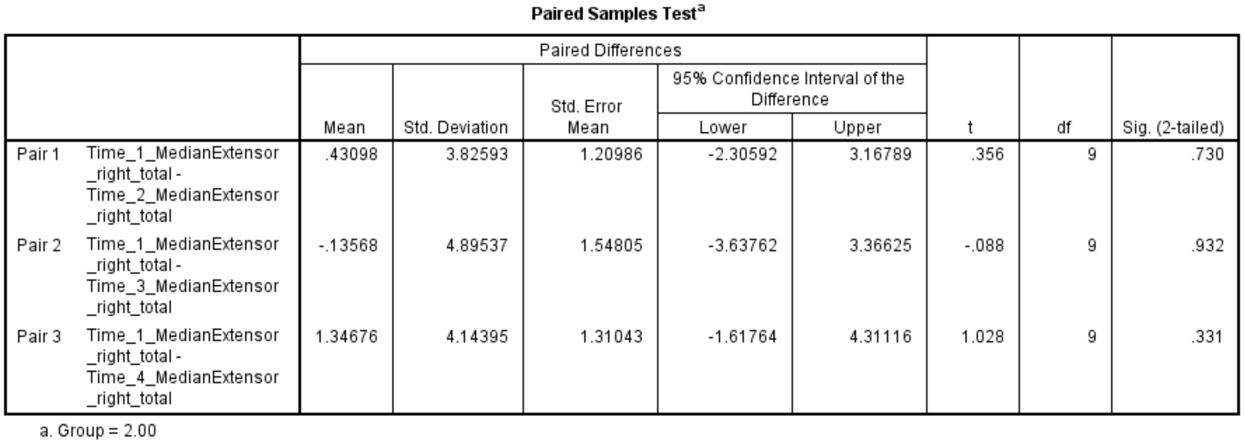
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_MedianExtensor_right_total	Equal variances assumed	.666	.425	.155	18	.878	.98485	6.34192	-12.33904	14.30874
	Equal variances not assumed			.155	17.715	.878	.98485	6.34192	-12.35443	14.32413
Time_2_MedianExtensor_right_total	Equal variances assumed	.091	.766	.409	18	.687	2.59167	6.33022	-10.70762	15.89096
	Equal variances not assumed			.409	17.730	.687	2.59167	6.33022	-10.72214	15.90548
Time_3_MedianExtensor_right_total	Equal variances assumed	.113	.741	-.119	18	.906	-.77833	6.51795	-14.47203	12.91536
	Equal variances not assumed			-.119	17.981	.906	-.77833	6.51795	-14.47305	12.91638
Time_4_MedianExtensor_right_total	Equal variances assumed	.090	.768	.013	18	.990	.08208	6.54963	-13.67817	13.84234
	Equal variances not assumed			.013	17.784	.990	.08208	6.54963	-13.69017	13.85434



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianExtensor_right_total - Time_2_MedianExtensor_right_total	-1.17583	4.26978	1.35022	-4.23025	1.87859	-.871	9	.406
Pair 2	Time_1_MedianExtensor_right_total - Time_3_MedianExtensor_right_total	1.62750	4.24624	1.34278	-1.41008	4.66508	1.212	9	.256
Pair 3	Time_1_MedianExtensor_right_total - Time_4_MedianExtensor_right_total	2.24952	4.98519	1.57646	-1.31667	5.81571	1.427	9	.187

a. Group = 1.00



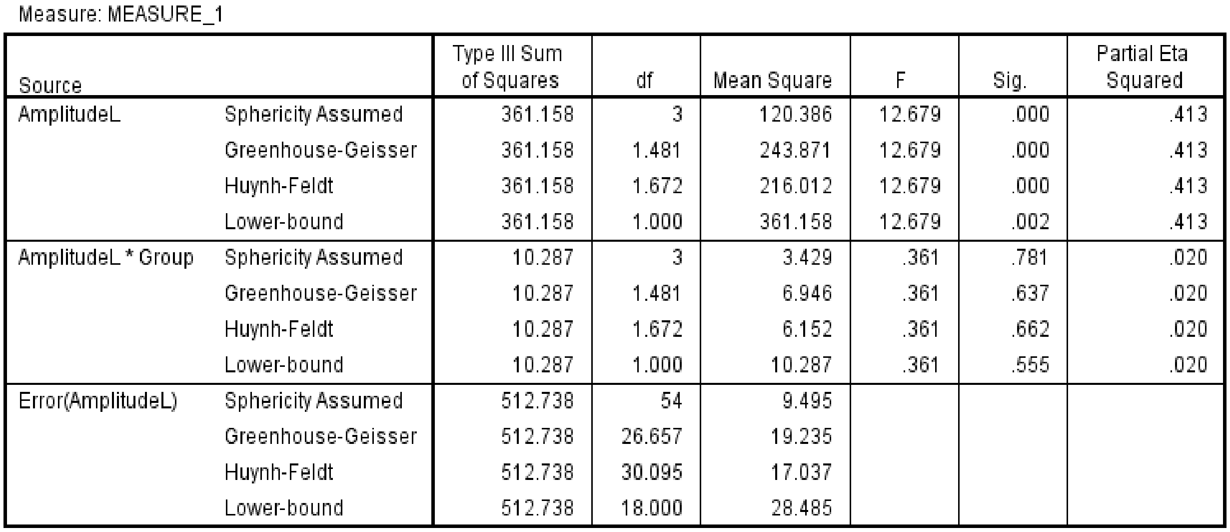
Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianExtensor_right_total - Time_2_MedianExtensor_right_total	.43098	3.82593	1.20986	-2.30592	3.16789	.356	9	.730
Pair 2	Time_1_MedianExtensor_right_total - Time_3_MedianExtensor_right_total	-.13568	4.89537	1.54805	-3.63762	3.36625	-.088	9	.932
Pair 3	Time_1_MedianExtensor_right_total - Time_4_MedianExtensor_right_total	1.34676	4.14395	1.31043	-1.61764	4.31116	1.028	9	.331

a. Group = 2.00

8. Amplitude (Non-dominant side)

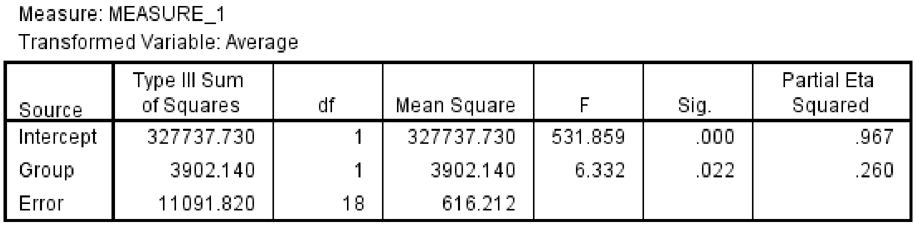
Tests of Within-Subjects Effects



Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AmplitudeL	Sphericity Assumed	361.158	3	120.386	12.679	.000	.413
	Greenhouse-Geisser	361.158	1.481	243.871	12.679	.000	.413
	Huynh-Feldt	361.158	1.672	216.012	12.679	.000	.413
	Lower-bound	361.158	1.000	361.158	12.679	.002	.413
AmplitudeL * Group	Sphericity Assumed	10.287	3	3.429	.361	.781	.020
	Greenhouse-Geisser	10.287	1.481	6.946	.361	.637	.020
	Huynh-Feldt	10.287	1.672	6.152	.361	.662	.020
	Lower-bound	10.287	1.000	10.287	.361	.555	.020
Error(AmplitudeL)	Sphericity Assumed	512.738	54	9.495			
	Greenhouse-Geisser	512.738	26.657	19.235			
	Huynh-Feldt	512.738	30.095	17.037			
	Lower-bound	512.738	18.000	28.485			

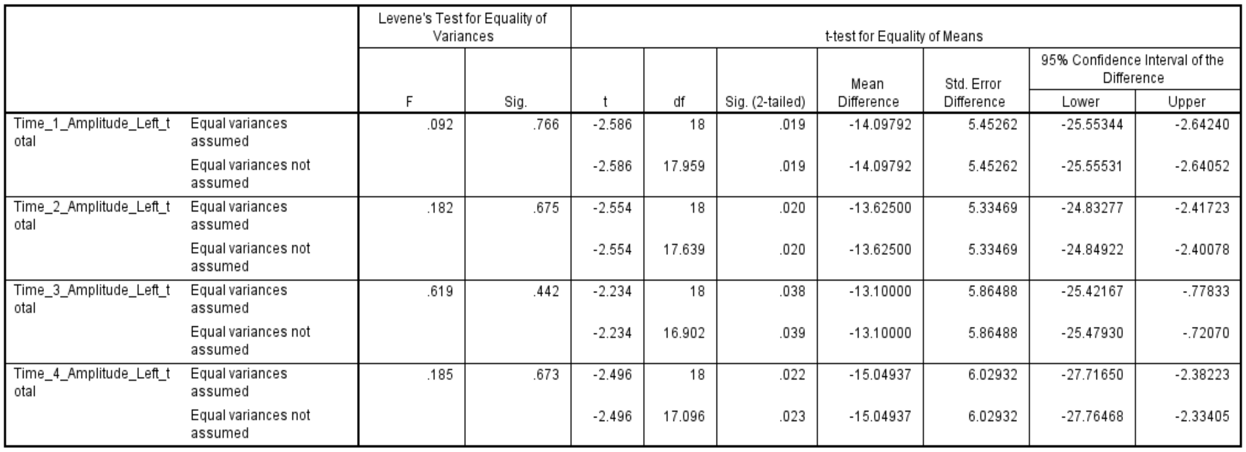
Tests of Between-Subjects Effects



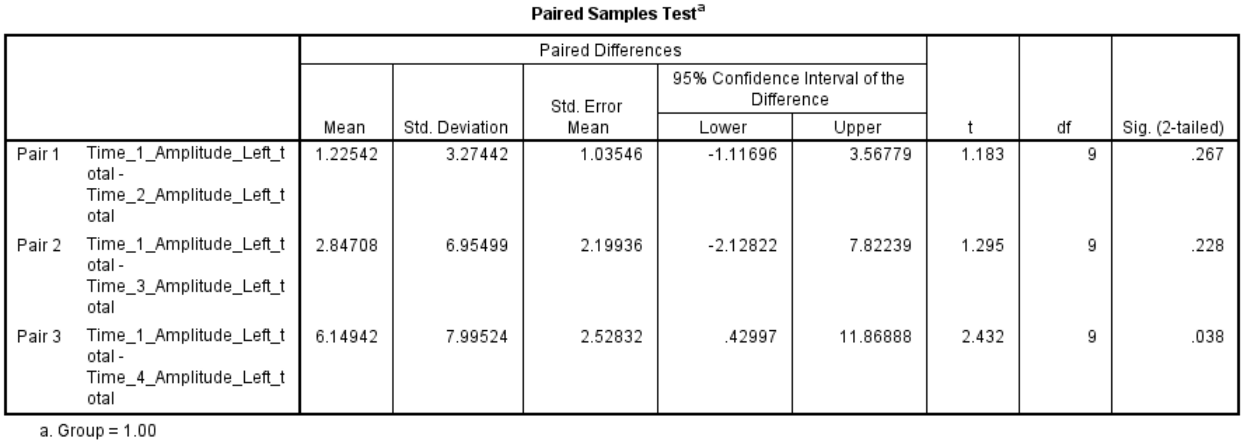
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	327737.730	1	327737.730	531.859	.000	.967
Group	3902.140	1	3902.140	6.332	.022	.260
Error	11091.820	18	616.212			

Independent Samples Test



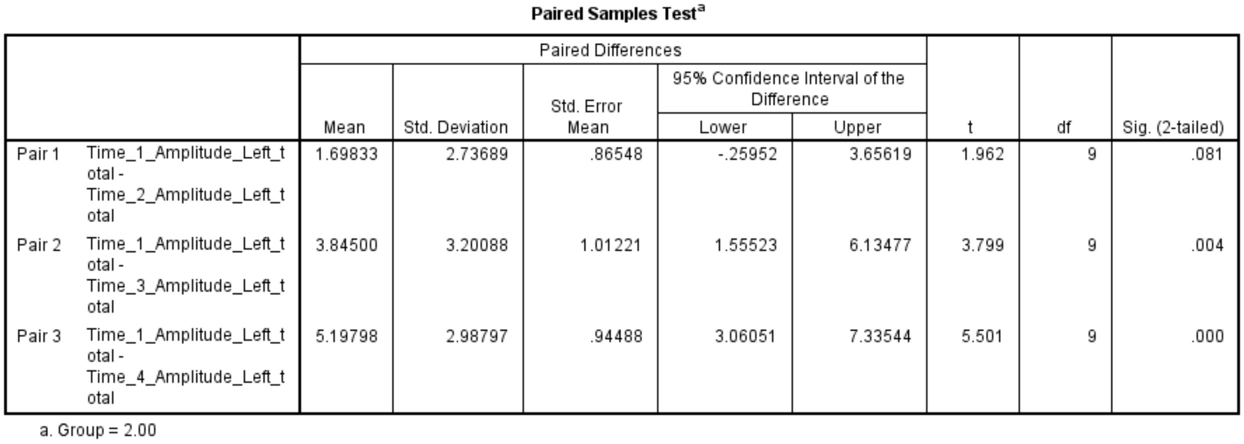
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_Amplitude_Left_total	Equal variances assumed	.092	.766	-2.586	18	.019	-14.09792	5.45262	-25.55344	-2.64240
	Equal variances not assumed			-2.586	17.959	.019	-14.09792	5.45262	-25.55531	-2.64052
Time_2_Amplitude_Left_total	Equal variances assumed	.182	.675	-2.554	18	.020	-13.62500	5.33469	-24.83277	-2.41723
	Equal variances not assumed			-2.554	17.639	.020	-13.62500	5.33469	-24.84922	-2.40078
Time_3_Amplitude_Left_total	Equal variances assumed	.619	.442	-2.234	18	.038	-13.10000	5.86488	-25.42167	-.77833
	Equal variances not assumed			-2.234	16.902	.039	-13.10000	5.86488	-25.47930	-.72070
Time_4_Amplitude_Left_total	Equal variances assumed	.185	.673	-2.496	18	.022	-15.04937	6.02932	-27.71650	-2.38223
	Equal variances not assumed			-2.496	17.096	.023	-15.04937	6.02932	-27.76468	-2.33405



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Time_1_Amplitude_Left_total - Time_2_Amplitude_Left_total	1.22542	3.27442	1.03546	-1.11696	3.56779	1.183	9	.267
Pair 2	Time_1_Amplitude_Left_total - Time_3_Amplitude_Left_total	2.84708	6.95499	2.19936	-2.12822	7.82239	1.295	9	.228
Pair 3	Time_1_Amplitude_Left_total - Time_4_Amplitude_Left_total	6.14942	7.99524	2.52832	.42997	11.86888	2.432	9	.038

a. Group = 1.00

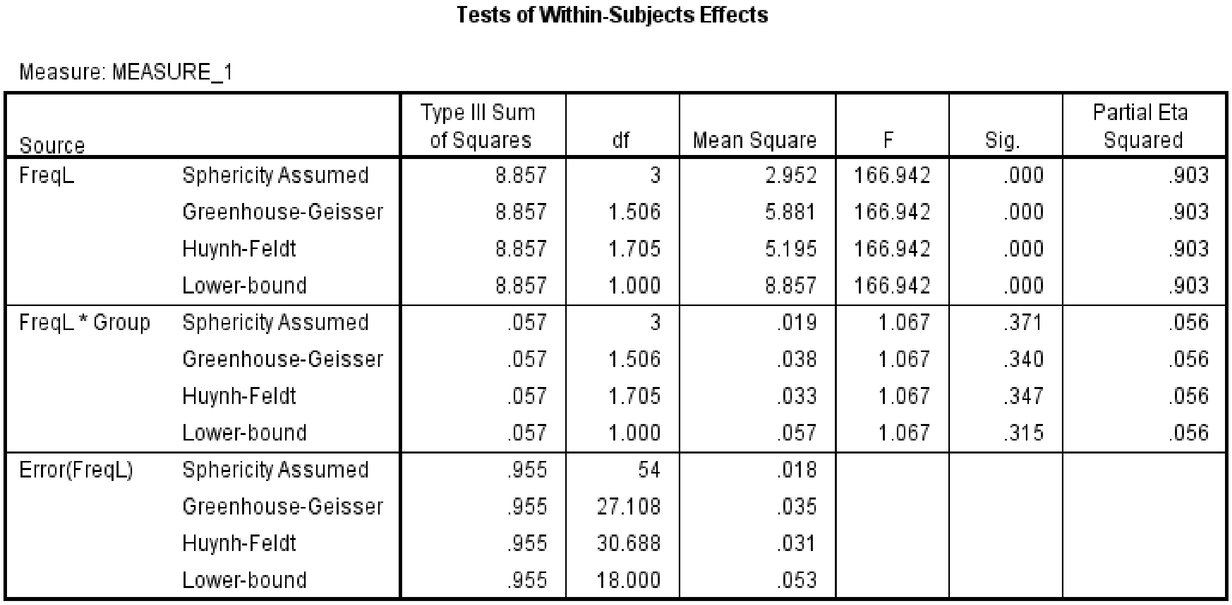


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Time_1_Amplitude_Left_total - Time_2_Amplitude_Left_total	1.69833	2.73689	.86548	-.25952	3.65619	1.962	9	.081
Pair 2	Time_1_Amplitude_Left_total - Time_3_Amplitude_Left_total	3.84500	3.20088	1.01221	1.55523	6.13477	3.799	9	.004
Pair 3	Time_1_Amplitude_Left_total - Time_4_Amplitude_Left_total	5.19798	2.98797	.94488	3.06051	7.33544	5.501	9	.000

a. Group = 2.00

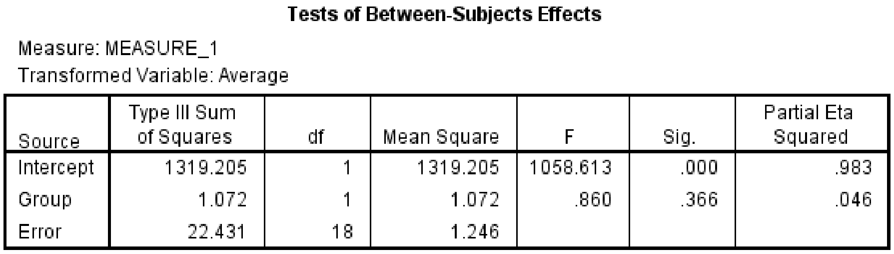
9. Frequency (Non-dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

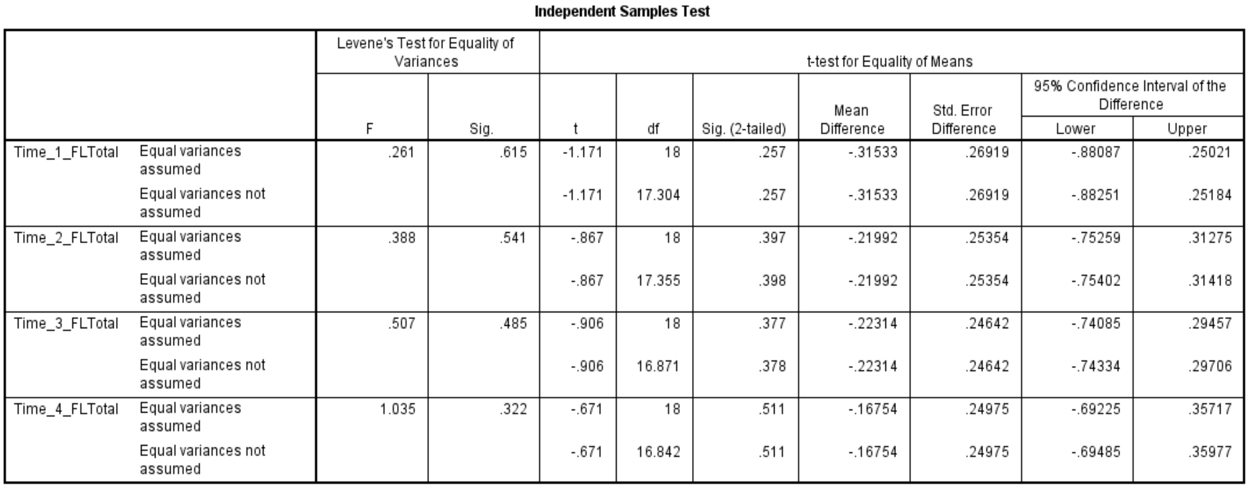
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
FreqL	Sphericity Assumed	8.857	3	2.952	166.942	.000	.903
	Greenhouse-Geisser	8.857	1.506	5.881	166.942	.000	.903
	Huynh-Feldt	8.857	1.705	5.195	166.942	.000	.903
	Lower-bound	8.857	1.000	8.857	166.942	.000	.903
FreqL * Group	Sphericity Assumed	.057	3	.019	1.067	.371	.056
	Greenhouse-Geisser	.057	1.506	.038	1.067	.340	.056
	Huynh-Feldt	.057	1.705	.033	1.067	.347	.056
	Lower-bound	.057	1.000	.057	1.067	.315	.056
Error(FreqL)	Sphericity Assumed	.955	54	.018			
	Greenhouse-Geisser	.955	27.108	.035			
	Huynh-Feldt	.955	30.688	.031			
	Lower-bound	.955	18.000	.053			



Tests of Between-Subjects Effects

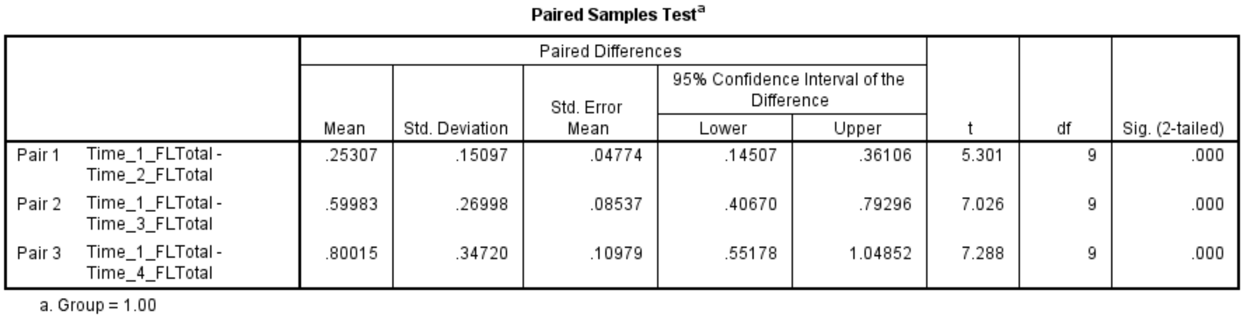
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1319.205	1	1319.205	1058.613	.000	.983
Group	1.072	1	1.072	.860	.366	.046
Error	22.431	18	1.246			



Independent Samples Test

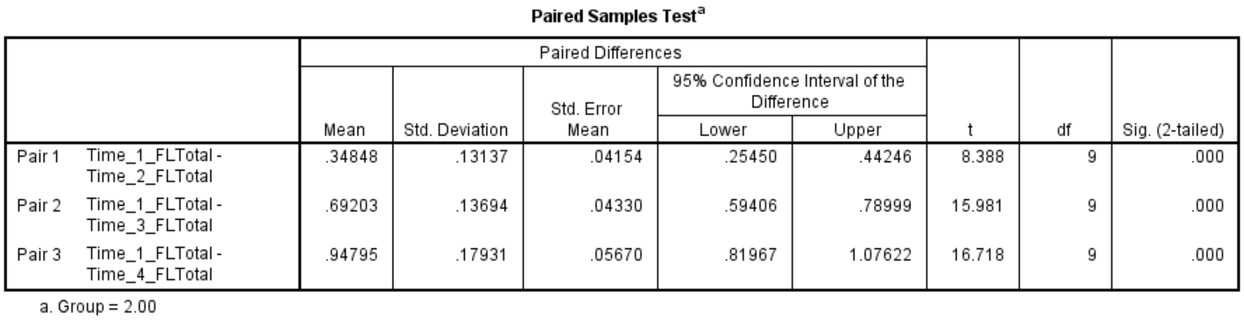
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_FLTotal	Equal variances assumed	.261	.615	-1.171	18	.257	-.31533	.26919	-.88087	.25021
	Equal variances not assumed			-1.171	17.304	.257	-.31533	.26919	-.88251	.25184
Time_2_FLTotal	Equal variances assumed	.388	.541	-.867	18	.397	-.21992	.25354	-.75259	.31275
	Equal variances not assumed			-.867	17.355	.398	-.21992	.25354	-.75402	.31418
Time_3_FLTotal	Equal variances assumed	.507	.485	-.906	18	.377	-.22314	.24642	-.74085	.29457
	Equal variances not assumed			-.906	16.871	.378	-.22314	.24642	-.74334	.29706
Time_4_FLTotal	Equal variances assumed	1.035	.322	-.671	18	.511	-.16754	.24975	-.69225	.35717
	Equal variances not assumed			-.671	16.842	.511	-.16754	.24975	-.69485	.35977



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_FLTotal - Time_2_FLTotal	.25307	.15097	.04774	.14507	.36106	5.301	9	.000
Pair 2	Time_1_FLTotal - Time_3_FLTotal	.59983	.26998	.08537	.40670	.79296	7.026	9	.000
Pair 3	Time_1_FLTotal - Time_4_FLTotal	.80015	.34720	.10979	.55178	1.04852	7.288	9	.000

a. Group = 1.00

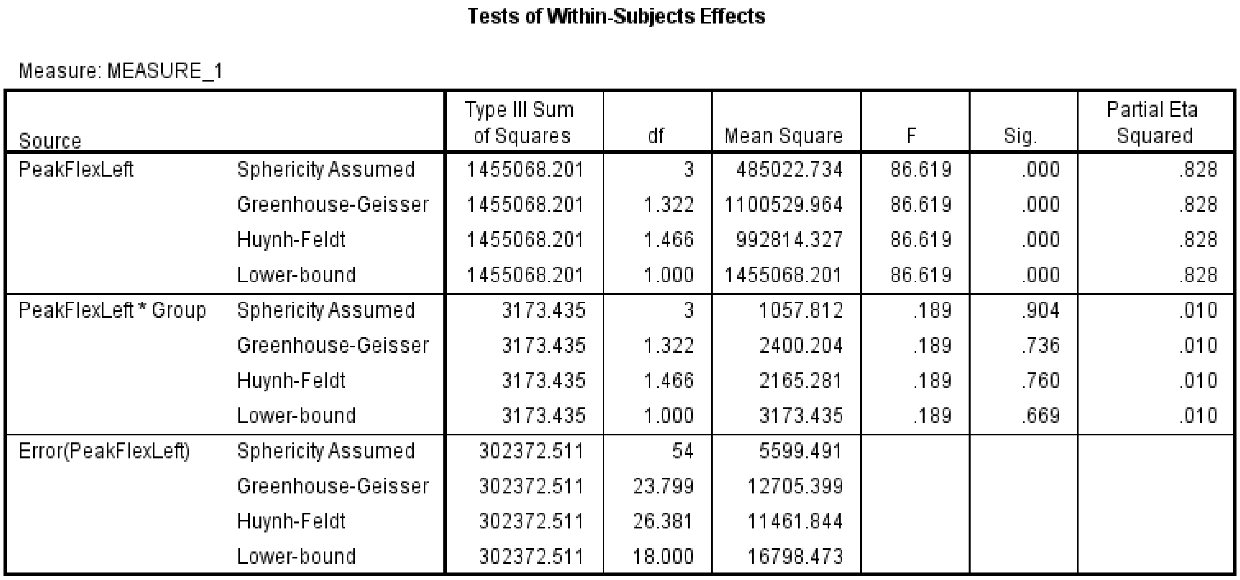


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_FLTotal - Time_2_FLTotal	.34848	.13137	.04154	.25450	.44246	8.388	9	.000
Pair 2	Time_1_FLTotal - Time_3_FLTotal	.69203	.13694	.04330	.59406	.78999	15.981	9	.000
Pair 3	Time_1_FLTotal - Time_4_FLTotal	.94795	.17931	.05670	.81967	1.07622	16.718	9	.000

a. Group = 2.00

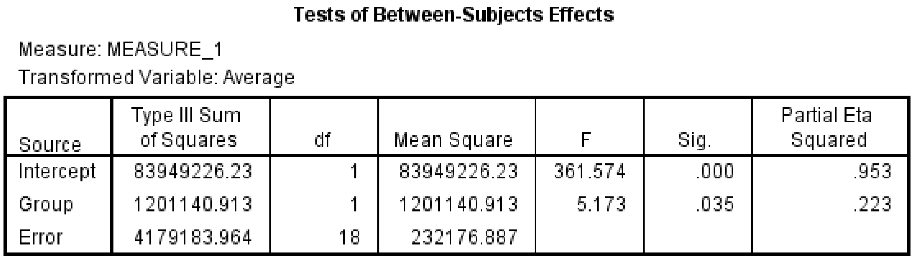
10. Peak Velocity Flexor (Non-dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

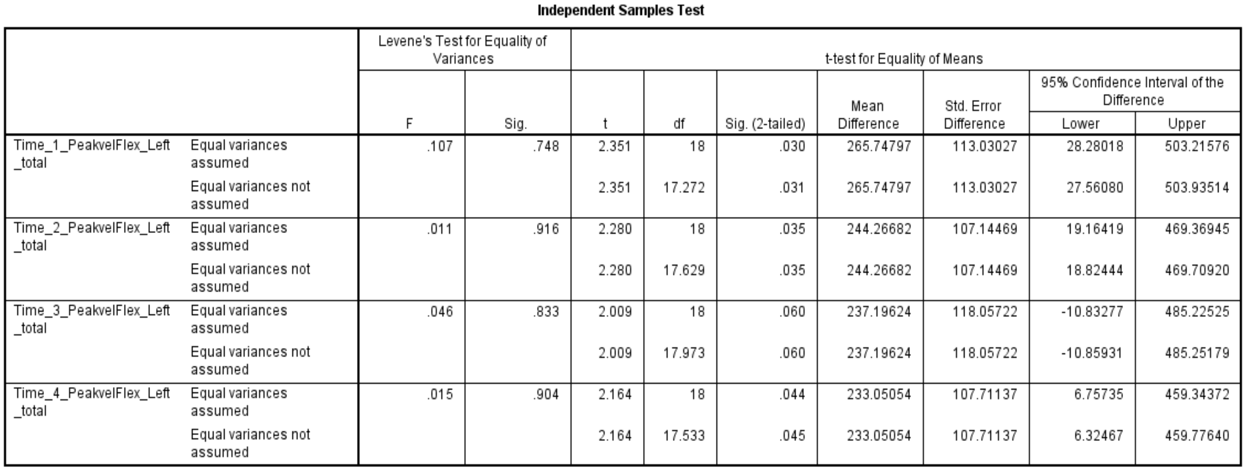
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PeakFlexLeft	Sphericity Assumed	1455068.201	3	485022.734	86.619	.000	.828
	Greenhouse-Geisser	1455068.201	1.322	1100529.964	86.619	.000	.828
	Huynh-Feldt	1455068.201	1.466	992814.327	86.619	.000	.828
	Lower-bound	1455068.201	1.000	1455068.201	86.619	.000	.828
PeakFlexLeft * Group	Sphericity Assumed	3173.435	3	1057.812	.189	.904	.010
	Greenhouse-Geisser	3173.435	1.322	2400.204	.189	.736	.010
	Huynh-Feldt	3173.435	1.466	2165.281	.189	.760	.010
	Lower-bound	3173.435	1.000	3173.435	.189	.669	.010
Error(PeakFlexLeft)	Sphericity Assumed	302372.511	54	5599.491			
	Greenhouse-Geisser	302372.511	23.799	12705.399			
	Huynh-Feldt	302372.511	26.381	11461.844			
	Lower-bound	302372.511	18.000	16798.473			



Tests of Between-Subjects Effects

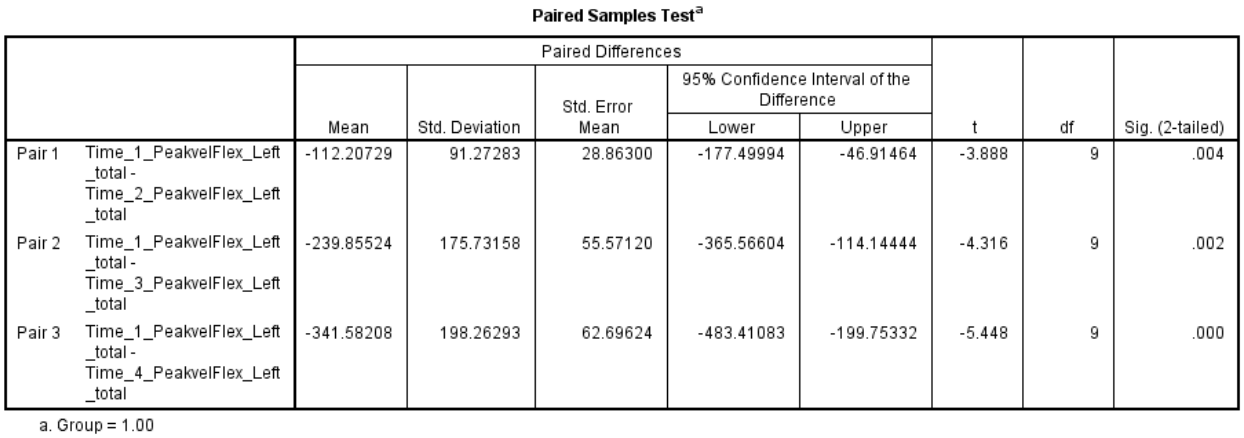
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	83949226.23	1	83949226.23	361.574	.000	.953
Group	1201140.913	1	1201140.913	5.173	.035	.223
Error	4179183.964	18	232176.887			



Independent Samples Test

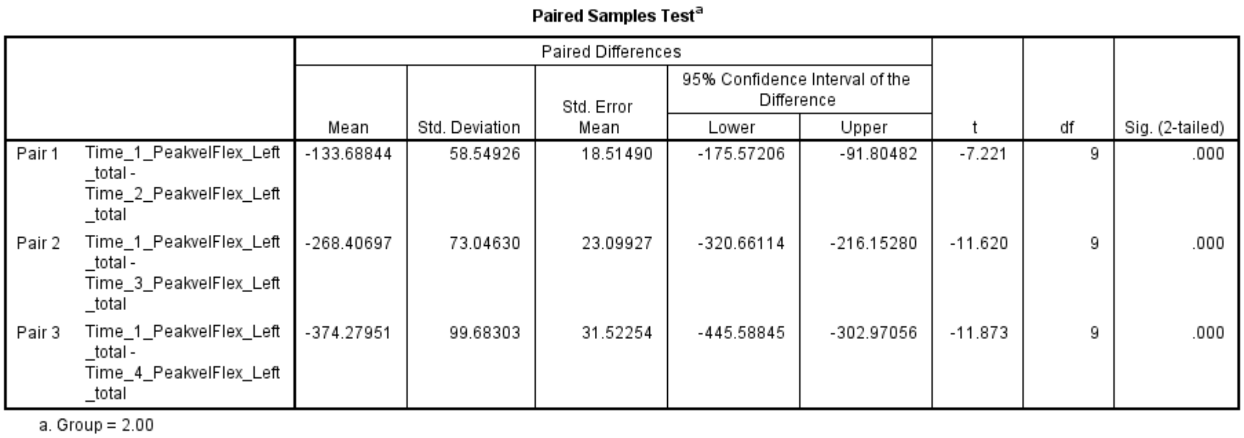
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_PeakvelFlex_Left_total	Equal variances assumed	.107	.748	2.351	18	.030	265.74797	113.03027	28.28018	503.21576
	Equal variances not assumed			2.351	17.272	.031	265.74797	113.03027	27.56080	503.93514
Time_2_PeakvelFlex_Left_total	Equal variances assumed	.011	.916	2.280	18	.035	244.26682	107.14469	19.16419	469.36945
	Equal variances not assumed			2.280	17.629	.035	244.26682	107.14469	18.82444	469.70920
Time_3_PeakvelFlex_Left_total	Equal variances assumed	.046	.833	2.009	18	.060	237.19624	118.05722	-10.83277	485.22525
	Equal variances not assumed			2.009	17.973	.060	237.19624	118.05722	-10.85931	485.25179
Time_4_PeakvelFlex_Left_total	Equal variances assumed	.015	.904	2.164	18	.044	233.05054	107.71137	6.75735	459.34372
	Equal variances not assumed			2.164	17.533	.045	233.05054	107.71137	6.32467	459.77640



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Time_1_PeakvelFlex_Left_total - Time_2_PeakvelFlex_Left_total	-112.20729	91.27283	28.86300	-177.49994	-46.91464	-3.888	9	.004
Pair 2	Time_1_PeakvelFlex_Left_total - Time_3_PeakvelFlex_Left_total	-239.85524	175.73158	55.57120	-365.56604	-114.14444	-4.316	9	.002
Pair 3	Time_1_PeakvelFlex_Left_total - Time_4_PeakvelFlex_Left_total	-341.58208	198.26293	62.69624	-483.41083	-199.75332	-5.448	9	.000

a. Group = 1.00

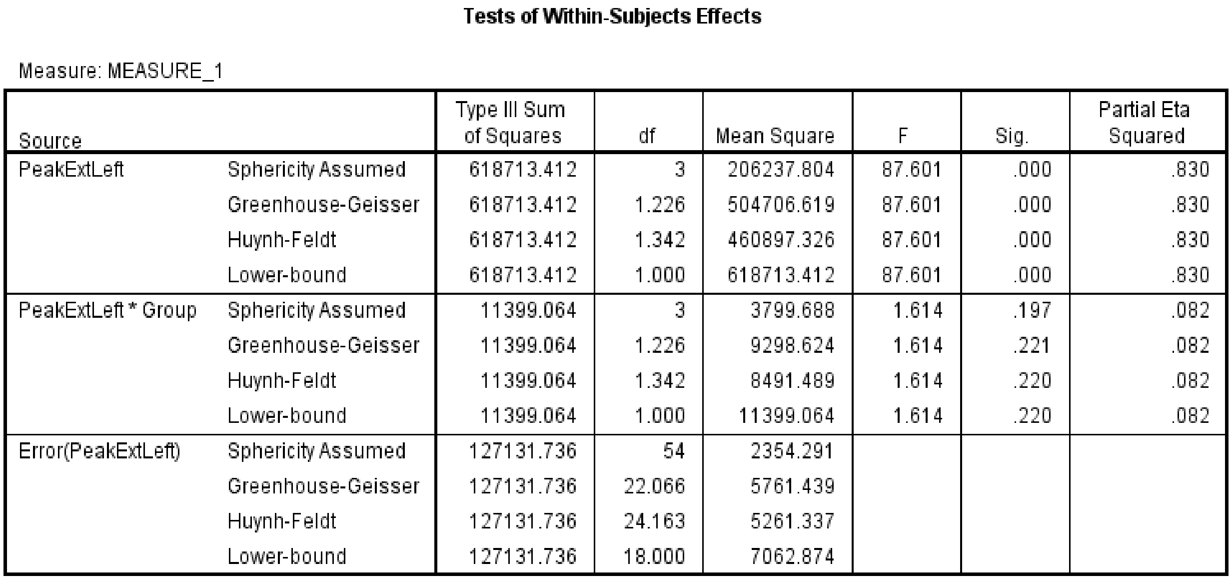


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Time_1_PeakvelFlex_Left_total - Time_2_PeakvelFlex_Left_total	-133.68844	58.54926	18.51490	-175.57206	-91.80482	-7.221	9	.000
Pair 2	Time_1_PeakvelFlex_Left_total - Time_3_PeakvelFlex_Left_total	-268.40697	73.04630	23.09927	-320.66114	-216.15280	-11.620	9	.000
Pair 3	Time_1_PeakvelFlex_Left_total - Time_4_PeakvelFlex_Left_total	-374.27951	99.68303	31.52254	-445.58845	-302.97056	-11.873	9	.000

a. Group = 2.00

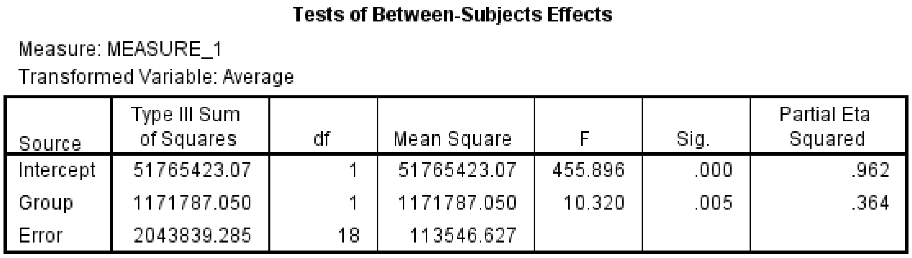
11. Peak Velocity Extensor (Non-dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

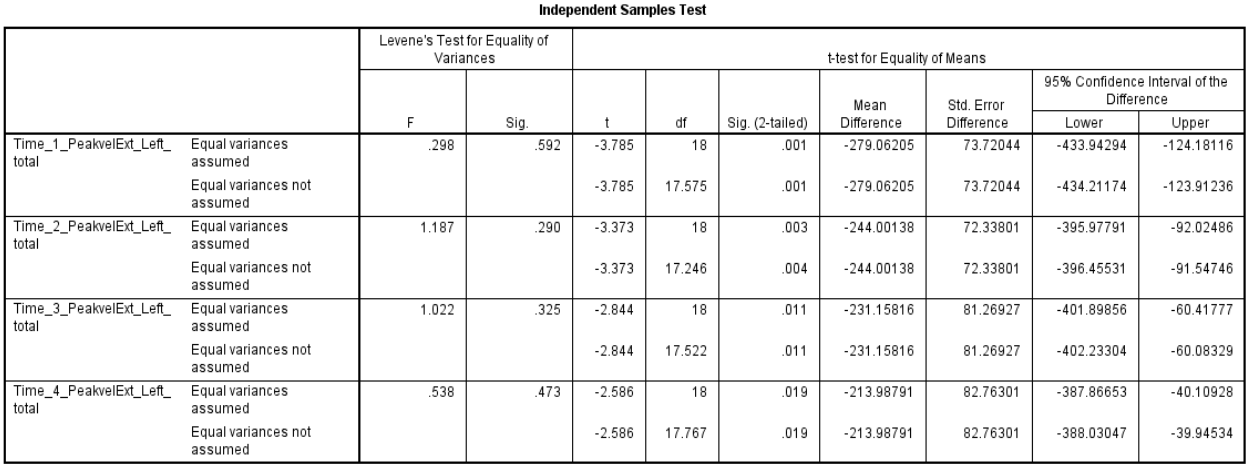
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
PeakExtLeft	Sphericity Assumed	618713.412	3	206237.804	87.601	.000	.830
	Greenhouse-Geisser	618713.412	1.226	504706.619	87.601	.000	.830
	Huynh-Feldt	618713.412	1.342	460897.326	87.601	.000	.830
	Lower-bound	618713.412	1.000	618713.412	87.601	.000	.830
PeakExtLeft * Group	Sphericity Assumed	11399.064	3	3799.688	1.614	.197	.082
	Greenhouse-Geisser	11399.064	1.226	9298.624	1.614	.221	.082
	Huynh-Feldt	11399.064	1.342	8491.489	1.614	.220	.082
	Lower-bound	11399.064	1.000	11399.064	1.614	.220	.082
Error(PeakExtLeft)	Sphericity Assumed	127131.736	54	2354.291			
	Greenhouse-Geisser	127131.736	22.066	5761.439			
	Huynh-Feldt	127131.736	24.163	5261.337			
	Lower-bound	127131.736	18.000	7062.874			



Tests of Between-Subjects Effects

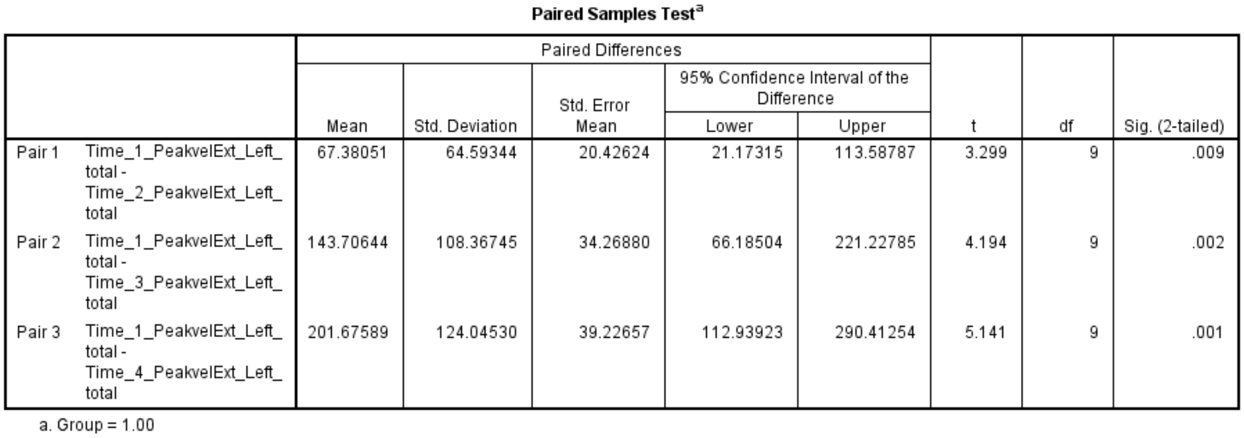
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	51765423.07	1	51765423.07	455.896	.000	.962
Group	1171787.050	1	1171787.050	10.320	.005	.364
Error	2043839.285	18	113546.627			



Independent Samples Test

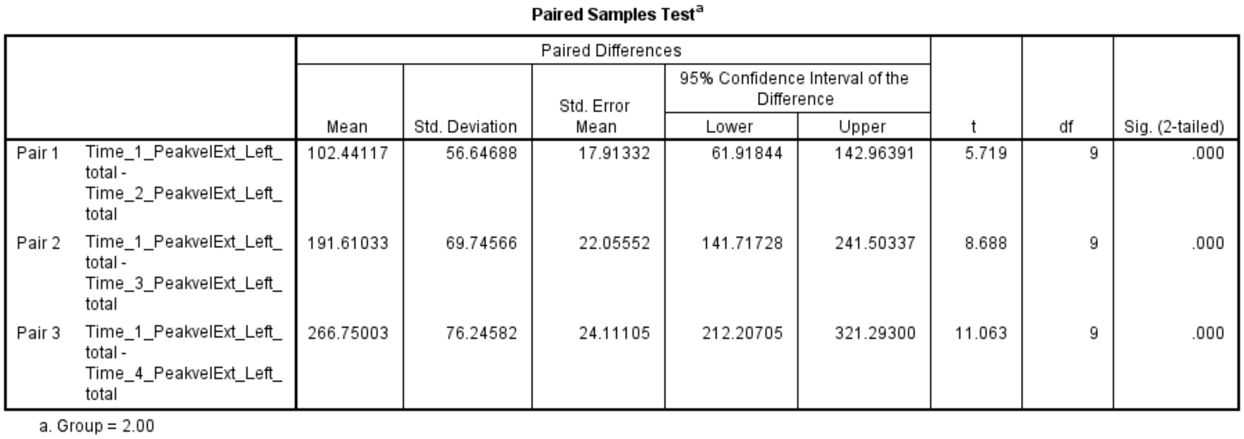
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_PeakvelExt_Left_total	Equal variances assumed	.298	.592	-3.785	18	.001	-279.06205	73.72044	-433.94294	-124.18116
	Equal variances not assumed			-3.785	17.575	.001	-279.06205	73.72044	-434.21174	-123.91236
Time_2_PeakvelExt_Left_total	Equal variances assumed	1.187	.290	-3.373	18	.003	-244.00138	72.33801	-395.97791	-92.02486
	Equal variances not assumed			-3.373	17.246	.004	-244.00138	72.33801	-396.45531	-91.54746
Time_3_PeakvelExt_Left_total	Equal variances assumed	1.022	.325	-2.844	18	.011	-231.15816	81.26927	-401.89856	-60.41777
	Equal variances not assumed			-2.844	17.522	.011	-231.15816	81.26927	-402.23304	-60.08329
Time_4_PeakvelExt_Left_total	Equal variances assumed	.538	.473	-2.586	18	.019	-213.98791	82.76301	-387.86653	-40.10928
	Equal variances not assumed			-2.586	17.767	.019	-213.98791	82.76301	-388.03047	-39.94534



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_PeakvelExt_Left_total - Time_2_PeakvelExt_Left_total	67.38051	64.59344	20.42624	21.17315	113.58787	3.299	9	.009
Pair 2	Time_1_PeakvelExt_Left_total - Time_3_PeakvelExt_Left_total	143.70644	108.36745	34.26880	66.18504	221.22785	4.194	9	.002
Pair 3	Time_1_PeakvelExt_Left_total - Time_4_PeakvelExt_Left_total	201.67589	124.04530	39.22657	112.93923	290.41254	5.141	9	.001

a. Group = 1.00

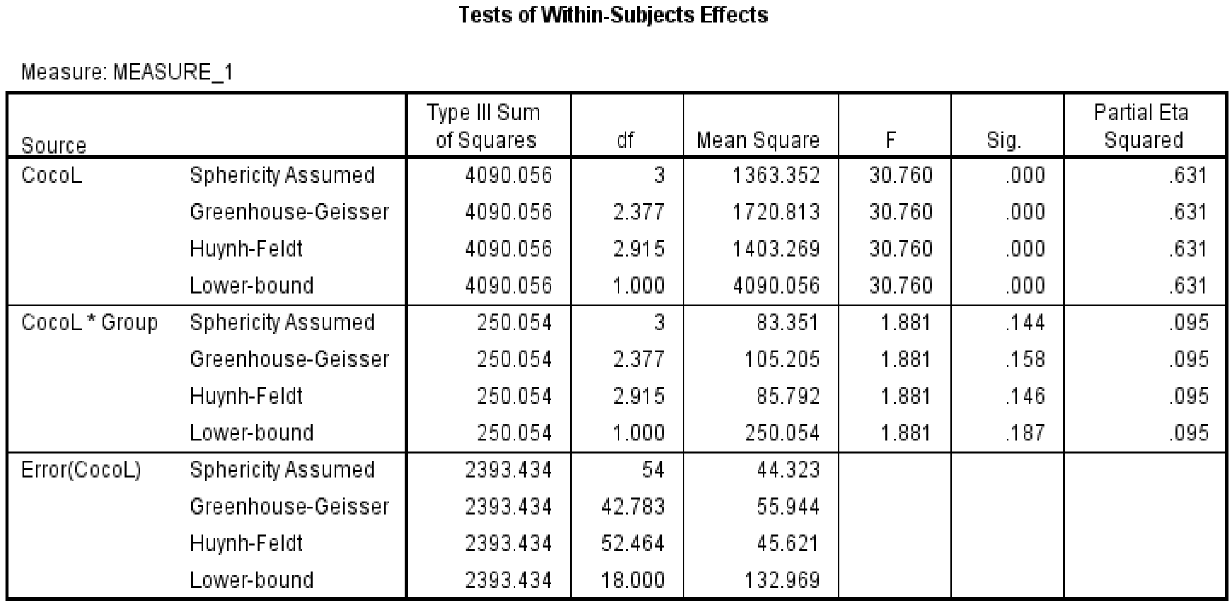


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_PeakvelExt_Left_total - Time_2_PeakvelExt_Left_total	102.44117	56.64688	17.91332	61.91844	142.96391	5.719	9	.000
Pair 2	Time_1_PeakvelExt_Left_total - Time_3_PeakvelExt_Left_total	191.61033	69.74566	22.05552	141.71728	241.50337	8.688	9	.000
Pair 3	Time_1_PeakvelExt_Left_total - Time_4_PeakvelExt_Left_total	266.75003	76.24582	24.11105	212.20705	321.29300	11.063	9	.000

a. Group = 2.00

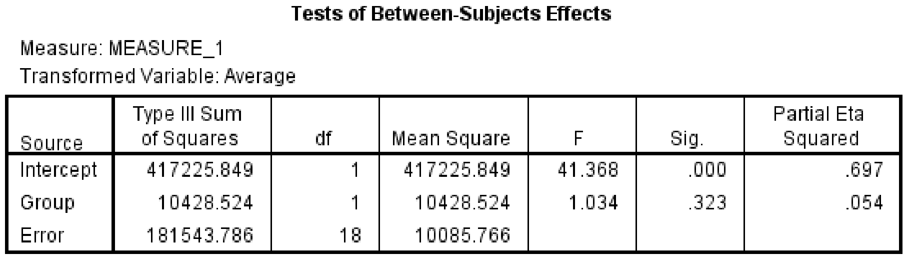
12. Co-contraction (Non-dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

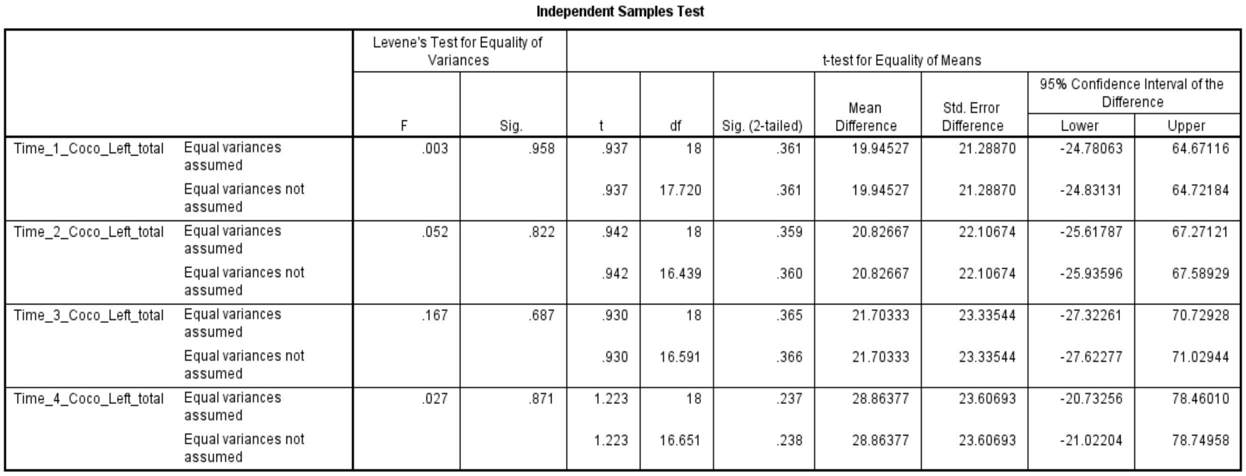
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
CocoL	Sphericity Assumed	4090.056	3	1363.352	30.760	.000	.631
	Greenhouse-Geisser	4090.056	2.377	1720.813	30.760	.000	.631
	Huynh-Feldt	4090.056	2.915	1403.269	30.760	.000	.631
	Lower-bound	4090.056	1.000	4090.056	30.760	.000	.631
CocoL * Group	Sphericity Assumed	250.054	3	83.351	1.881	.144	.095
	Greenhouse-Geisser	250.054	2.377	105.205	1.881	.158	.095
	Huynh-Feldt	250.054	2.915	85.792	1.881	.146	.095
	Lower-bound	250.054	1.000	250.054	1.881	.187	.095
Error(CocoL)	Sphericity Assumed	2393.434	54	44.323			
	Greenhouse-Geisser	2393.434	42.783	55.944			
	Huynh-Feldt	2393.434	52.464	45.621			
	Lower-bound	2393.434	18.000	132.969			



Tests of Between-Subjects Effects

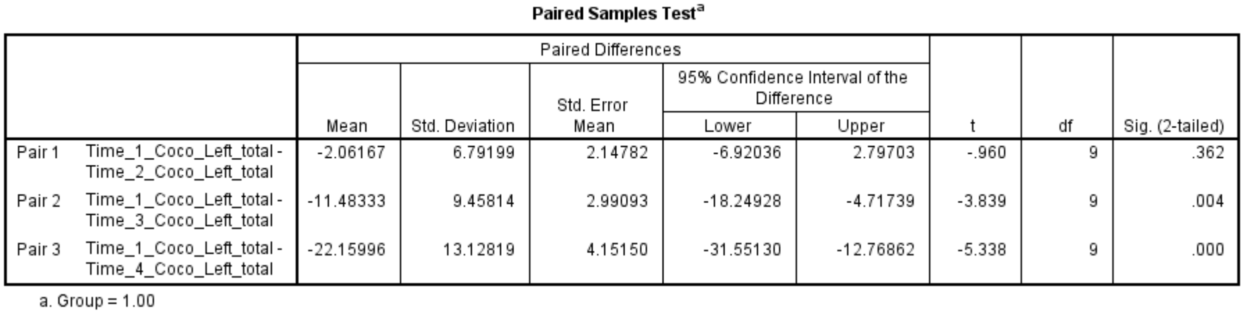
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	417225.849	1	417225.849	41.368	.000	.697
Group	10428.524	1	10428.524	1.034	.323	.054
Error	181543.786	18	10085.766			



Independent Samples Test

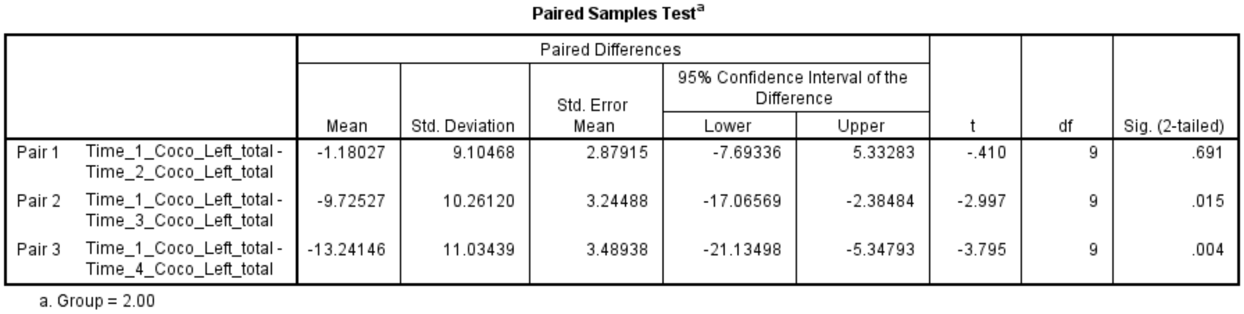
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_Coco_Left_total	Equal variances assumed	.003	.958	.937	18	.361	19.94527	21.28870	-24.78063	64.67116
	Equal variances not assumed			.937	17.720	.361	19.94527	21.28870	-24.83131	64.72184
Time_2_Coco_Left_total	Equal variances assumed	.052	.822	.942	18	.359	20.82667	22.10674	-25.61787	67.27121
	Equal variances not assumed			.942	16.439	.360	20.82667	22.10674	-25.93596	67.58929
Time_3_Coco_Left_total	Equal variances assumed	.167	.687	.930	18	.365	21.70333	23.33544	-27.32261	70.72928
	Equal variances not assumed			.930	16.591	.366	21.70333	23.33544	-27.62277	71.02944
Time_4_Coco_Left_total	Equal variances assumed	.027	.871	1.223	18	.237	28.86377	23.60693	-20.73256	78.46010
	Equal variances not assumed			1.223	16.651	.238	28.86377	23.60693	-21.02204	78.74958



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Time_1_Coco_Left_total - Time_2_Coco_Left_total	-2.06167	6.79199	2.14782	-6.92036	2.79703	-.960	9	.362
Pair 2	Time_1_Coco_Left_total - Time_3_Coco_Left_total	-11.48333	9.45814	2.99093	-18.24928	-4.71739	-3.839	9	.004
Pair 3	Time_1_Coco_Left_total - Time_4_Coco_Left_total	-22.15996	13.12819	4.15150	-31.55130	-12.76862	-5.338	9	.000

a. Group = 1.00

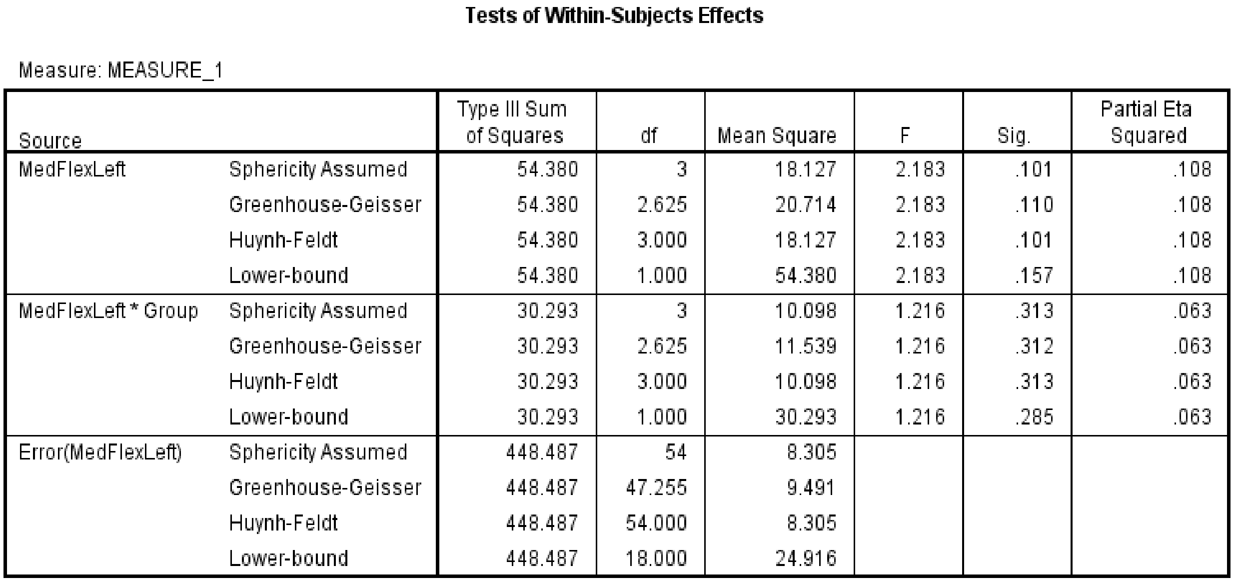


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Time_1_Coco_Left_total - Time_2_Coco_Left_total	-1.18027	9.10468	2.87915	-7.69336	5.33283	-.410	9	.691
Pair 2	Time_1_Coco_Left_total - Time_3_Coco_Left_total	-9.72527	10.26120	3.24488	-17.06569	-2.38484	-2.997	9	.015
Pair 3	Time_1_Coco_Left_total - Time_4_Coco_Left_total	-13.24146	11.03439	3.48938	-21.13498	-5.34793	-3.795	9	.004

a. Group = 2.00

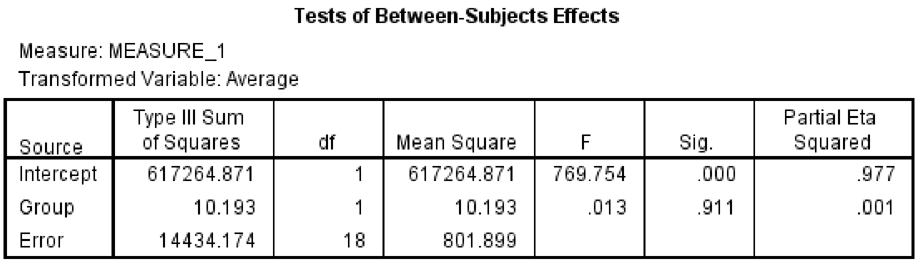
13. Median Frequency Flexor (Non-dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MedFlexLeft	Sphericity Assumed	54.380	3	18.127	2.183	.101	.108
	Greenhouse-Geisser	54.380	2.625	20.714	2.183	.110	.108
	Huynh-Feldt	54.380	3.000	18.127	2.183	.101	.108
	Lower-bound	54.380	1.000	54.380	2.183	.157	.108
MedFlexLeft * Group	Sphericity Assumed	30.293	3	10.098	1.216	.313	.063
	Greenhouse-Geisser	30.293	2.625	11.539	1.216	.312	.063
	Huynh-Feldt	30.293	3.000	10.098	1.216	.313	.063
	Lower-bound	30.293	1.000	30.293	1.216	.285	.063
Error(MedFlexLeft)	Sphericity Assumed	448.487	54	8.305			
	Greenhouse-Geisser	448.487	47.255	9.491			
	Huynh-Feldt	448.487	54.000	8.305			
	Lower-bound	448.487	18.000	24.916			

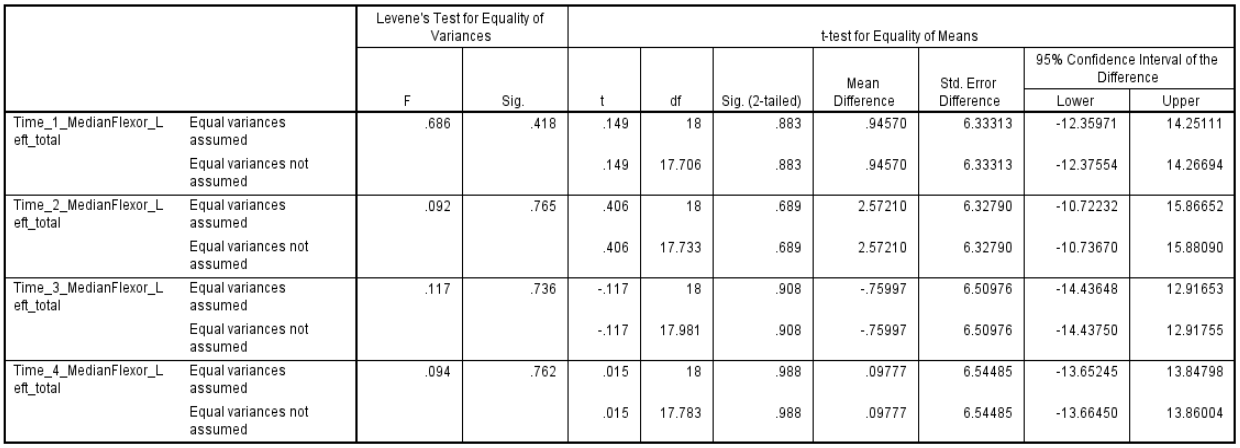


Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

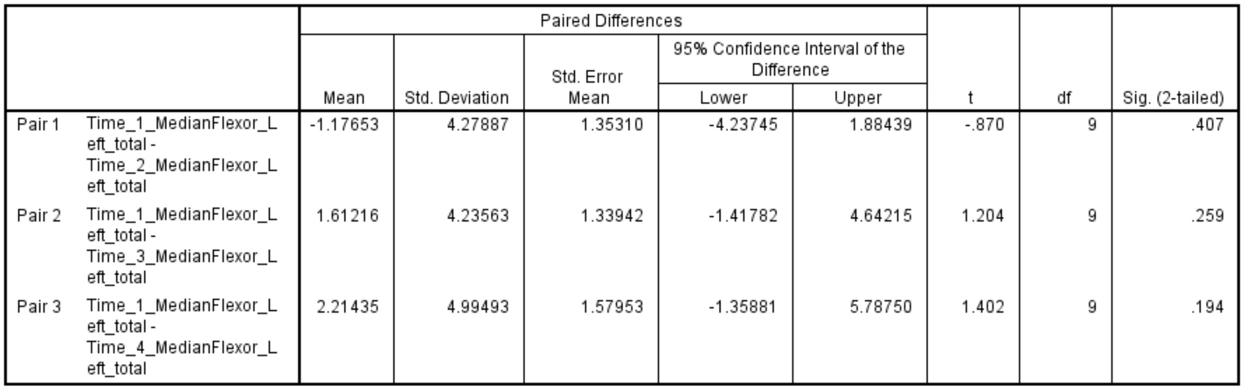
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	617264.871	1	617264.871	769.754	.000	.977
Group	10.193	1	10.193	.013	.911	.001
Error	14434.174	18	801.899			

Independent Samples Test



		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_MedianFlexor_Left_total	Equal variances assumed	.686	.418	.149	18	.883	.94570	6.33313	-12.35971	14.25111
	Equal variances not assumed			.149	17.706	.883	.94570	6.33313	-12.37554	14.26694
Time_2_MedianFlexor_Left_total	Equal variances assumed	.092	.765	.406	18	.689	2.57210	6.32790	-10.72232	15.86652
	Equal variances not assumed			.406	17.733	.689	2.57210	6.32790	-10.73670	15.88090
Time_3_MedianFlexor_Left_total	Equal variances assumed	.117	.736	-.117	18	.908	-.75997	6.50976	-14.43648	12.91653
	Equal variances not assumed			-.117	17.981	.908	-.75997	6.50976	-14.43750	12.91755
Time_4_MedianFlexor_Left_total	Equal variances assumed	.094	.762	.015	18	.988	.09777	6.54485	-13.65245	13.84798
	Equal variances not assumed			.015	17.783	.988	.09777	6.54485	-13.66450	13.86004

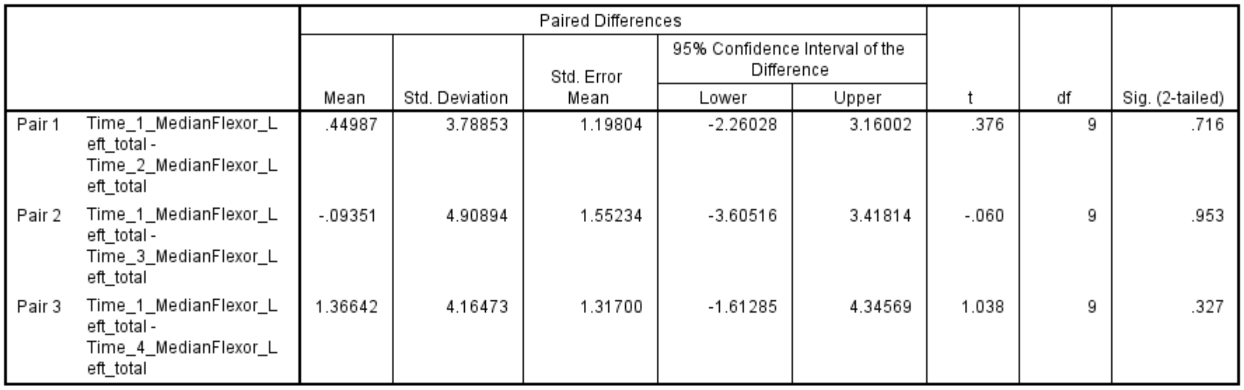
Paired Samples Test[a]



		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianFlexor_Left_total - Time_2_MedianFlexor_Left_total	-1.17653	4.27887	1.35310	-4.23745	1.88439	-.870	9	.407
Pair 2	Time_1_MedianFlexor_Left_total - Time_3_MedianFlexor_Left_total	1.61216	4.23563	1.33942	-1.41782	4.64215	1.204	9	.259
Pair 3	Time_1_MedianFlexor_Left_total - Time_4_MedianFlexor_Left_total	2.21435	4.99493	1.57953	-1.35881	5.78750	1.402	9	.194

a. Group = 1.00

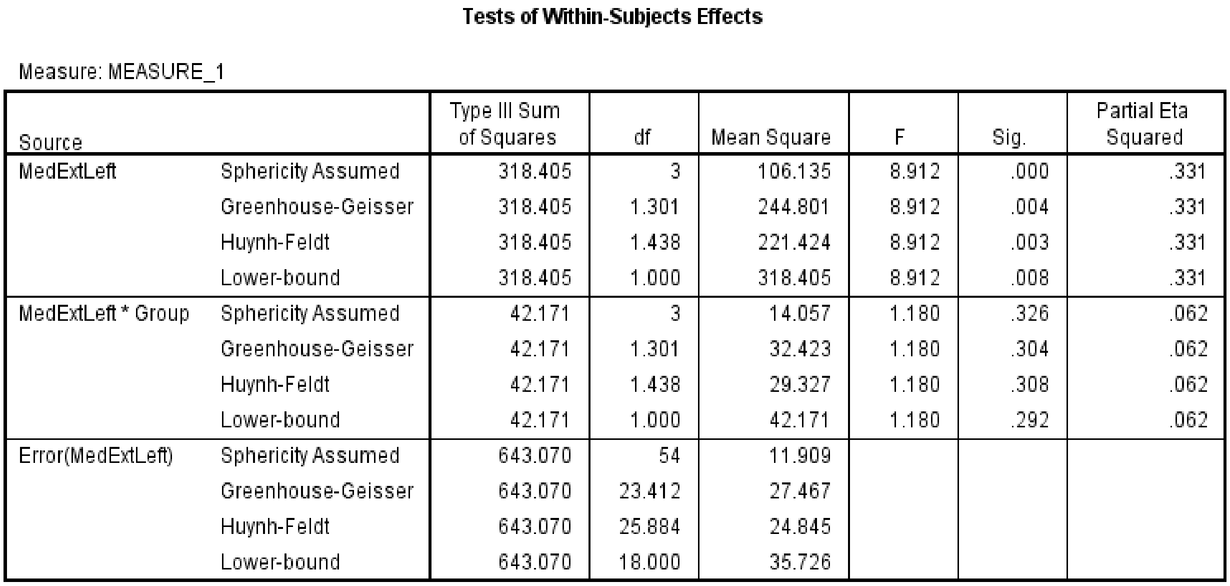
Paired Samples Test[a]



		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianFlexor_Left_total - Time_2_MedianFlexor_Left_total	.44987	3.78853	1.19804	-2.26028	3.16002	.376	9	.716
Pair 2	Time_1_MedianFlexor_Left_total - Time_3_MedianFlexor_Left_total	-.09351	4.90894	1.55234	-3.60516	3.41814	-.060	9	.953
Pair 3	Time_1_MedianFlexor_Left_total - Time_4_MedianFlexor_Left_total	1.36642	4.16473	1.31700	-1.61285	4.34569	1.038	9	.327

a. Group = 2.00

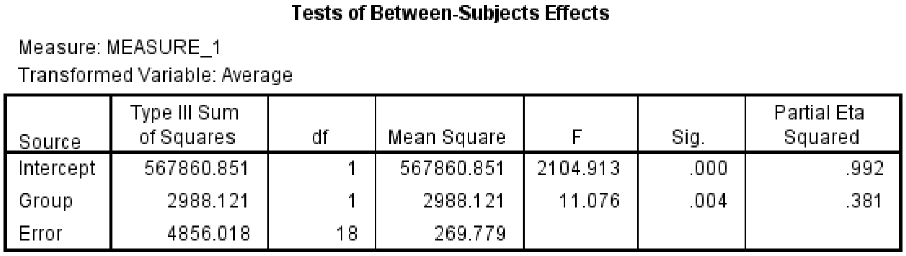
14. Median Frequency Extensor (Non-dominant side)



Tests of Within-Subjects Effects

Measure: MEASURE_1

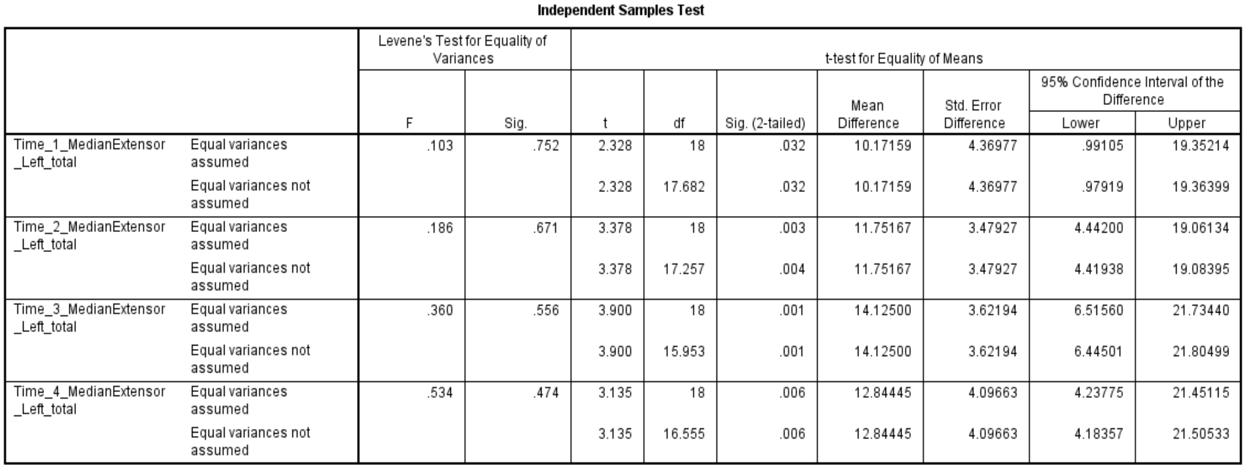
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MedExtLeft	Sphericity Assumed	318.405	3	106.135	8.912	.000	.331
	Greenhouse-Geisser	318.405	1.301	244.801	8.912	.004	.331
	Huynh-Feldt	318.405	1.438	221.424	8.912	.003	.331
	Lower-bound	318.405	1.000	318.405	8.912	.008	.331
MedExtLeft * Group	Sphericity Assumed	42.171	3	14.057	1.180	.326	.062
	Greenhouse-Geisser	42.171	1.301	32.423	1.180	.304	.062
	Huynh-Feldt	42.171	1.438	29.327	1.180	.308	.062
	Lower-bound	42.171	1.000	42.171	1.180	.292	.062
Error(MedExtLeft)	Sphericity Assumed	643.070	54	11.909			
	Greenhouse-Geisser	643.070	23.412	27.467			
	Huynh-Feldt	643.070	25.884	24.845			
	Lower-bound	643.070	18.000	35.726			



Tests of Between-Subjects Effects

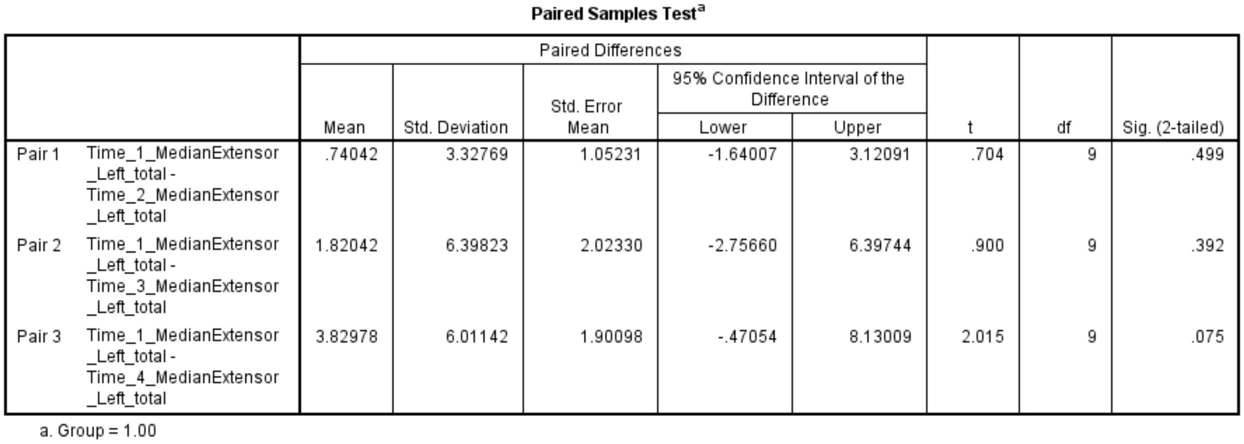
Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	567860.851	1	567860.851	2104.913	.000	.992
Group	2988.121	1	2988.121	11.076	.004	.381
Error	4856.018	18	269.779			



Independent Samples Test

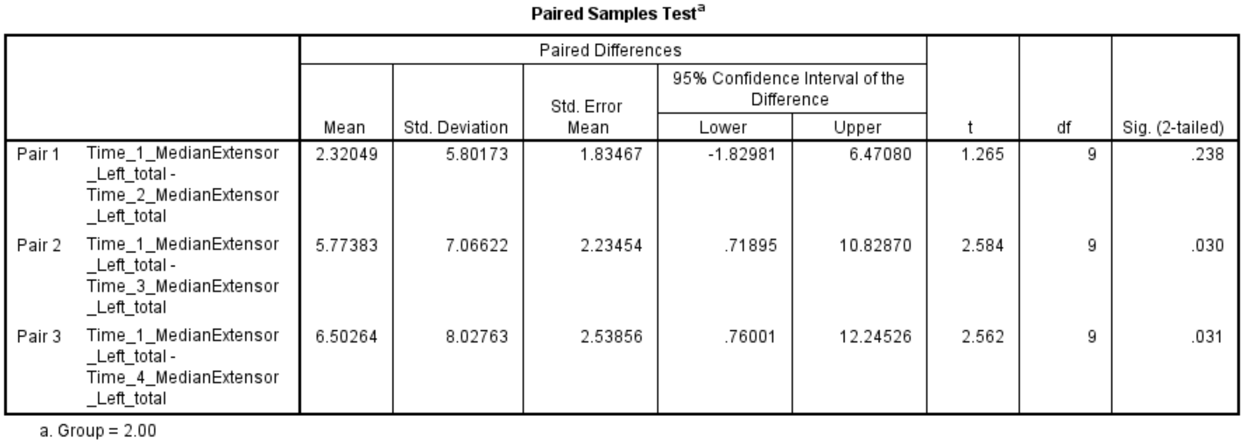
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_1_MedianExtensor _Left_total	Equal variances assumed	.103	.752	2.328	18	.032	10.17159	4.36977	.99105	19.35214
	Equal variances not assumed			2.328	17.682	.032	10.17159	4.36977	.97919	19.36399
Time_2_MedianExtensor _Left_total	Equal variances assumed	.186	.671	3.378	18	.003	11.75167	3.47927	4.44200	19.06134
	Equal variances not assumed			3.378	17.257	.004	11.75167	3.47927	4.41938	19.08395
Time_3_MedianExtensor _Left_total	Equal variances assumed	.360	.556	3.900	18	.001	14.12500	3.62194	6.51560	21.73440
	Equal variances not assumed			3.900	15.953	.001	14.12500	3.62194	6.44501	21.80499
Time_4_MedianExtensor _Left_total	Equal variances assumed	.534	.474	3.135	18	.006	12.84445	4.09663	4.23775	21.45115
	Equal variances not assumed			3.135	16.555	.006	12.84445	4.09663	4.18357	21.50533



Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianExtensor _Left_total - Time_2_MedianExtensor _Left_total	.74042	3.32769	1.05231	-1.64007	3.12091	.704	9	.499
Pair 2	Time_1_MedianExtensor _Left_total - Time_3_MedianExtensor _Left_total	1.82042	6.39823	2.02330	-2.75660	6.39744	.900	9	.392
Pair 3	Time_1_MedianExtensor _Left_total - Time_4_MedianExtensor _Left_total	3.82978	6.01142	1.90098	-.47054	8.13009	2.015	9	.075

a. Group = 1.00

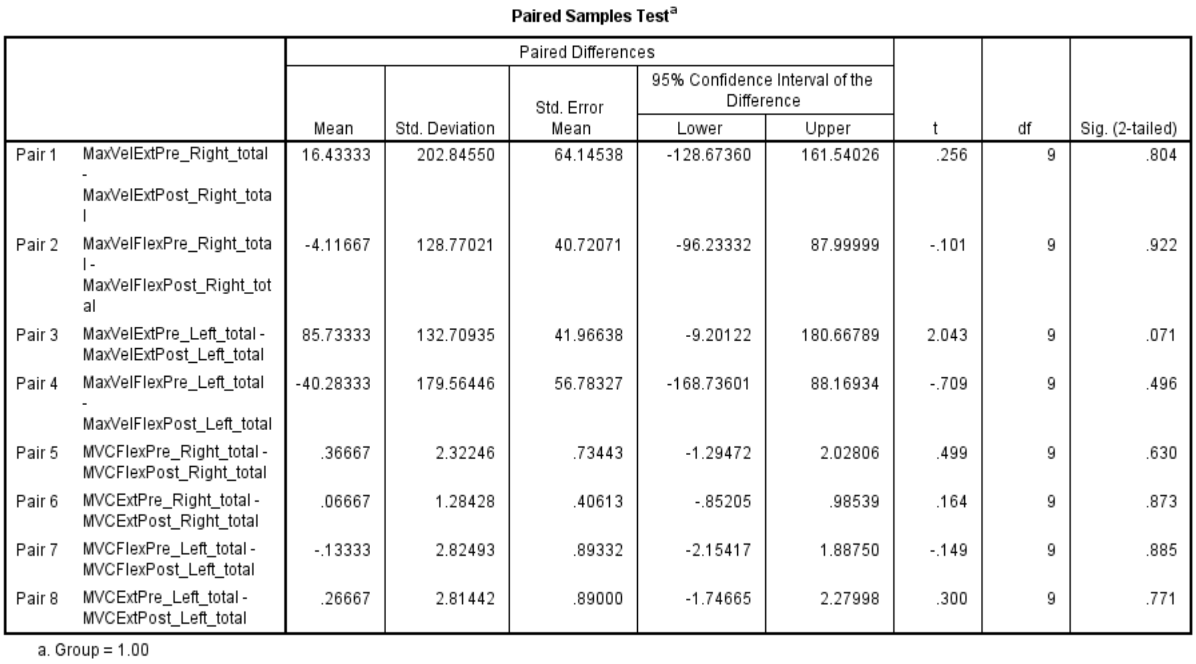


Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Time_1_MedianExtensor _Left_total - Time_2_MedianExtensor _Left_total	2.32049	5.80173	1.83467	-1.82981	6.47080	1.265	9	.238
Pair 2	Time_1_MedianExtensor _Left_total - Time_3_MedianExtensor _Left_total	5.77383	7.06622	2.23454	.71895	10.82870	2.584	9	.030
Pair 3	Time_1_MedianExtensor _Left_total - Time_4_MedianExtensor _Left_total	6.50264	8.02763	2.53856	.76001	12.24526	2.562	9	.031

a. Group = 2.00

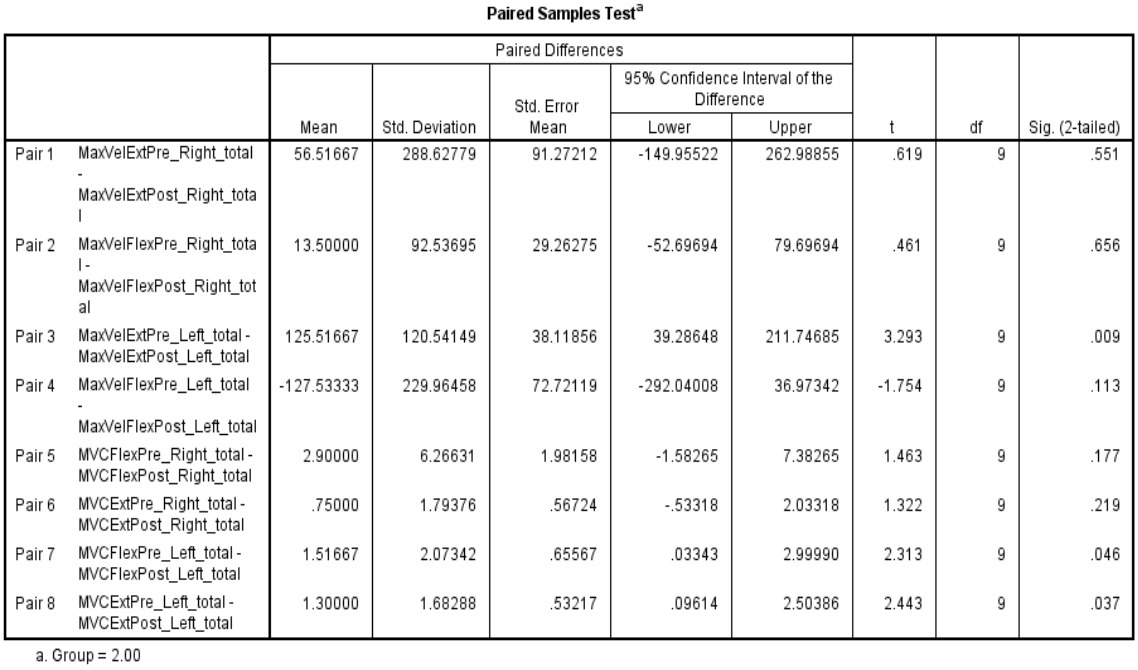
15. Peripheral fatigue



Paired Samples Test[a]

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	MaxVelExtPre_Right_total - MaxVelExtPost_Right_total	16.43333	202.84550	64.14538	-128.67360	161.54026	.256	9	.804
Pair 2	MaxVelFlexPre_Right_total - MaxVelFlexPost_Right_total	-4.11667	128.77021	40.72071	-96.23332	87.99999	-.101	9	.922
Pair 3	MaxVelExtPre_Left_total - MaxVelExtPost_Left_total	85.73333	132.70935	41.96638	-9.20122	180.66789	2.043	9	.071
Pair 4	MaxVelFlexPre_Left_total - MaxVelFlexPost_Left_total	-40.28333	179.56446	56.78327	-168.73601	88.16934	-.709	9	.496
Pair 5	MVCFlexPre_Right_total - MVCFlexPost_Right_total	.36667	2.32246	.73443	-1.29472	2.02806	.499	9	.630
Pair 6	MVCExtPre_Right_total - MVCExtPost_Right_total	.06667	1.28428	.40613	-.85205	.98539	.164	9	.873
Pair 7	MVCFlexPre_Left_total - MVCFlexPost_Left_total	-.13333	2.82493	.89332	-2.15417	1.88750	-.149	9	.885
Pair 8	MVCExtPre_Left_total - MVCExtPost_Left_total	.26667	2.81442	.89000	-1.74665	2.27998	.300	9	.771

a. Group = 1.00



Paired Samples Test[a]

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	MaxVelExtPre_Right_total - MaxVelExtPost_Right_total	56.51667	288.62779	91.27212	-149.95522	262.98855	.619	9	.551
Pair 2	MaxVelFlexPre_Right_total - MaxVelFlexPost_Right_total	13.50000	92.53695	29.26275	-52.69694	79.69694	.461	9	.656
Pair 3	MaxVelExtPre_Left_total - MaxVelExtPost_Left_total	125.51667	120.54149	38.11856	39.28648	211.74685	3.293	9	.009
Pair 4	MaxVelFlexPre_Left_total - MaxVelFlexPost_Left_total	-127.53333	229.96458	72.72119	-292.04008	36.97342	-1.754	9	.113
Pair 5	MVCFlexPre_Right_total - MVCFlexPost_Right_total	2.90000	6.26631	1.98158	-1.58265	7.38265	1.463	9	.177
Pair 6	MVCExtPre_Right_total - MVCExtPost_Right_total	.75000	1.79376	.56724	-.53318	2.03318	1.322	9	.219
Pair 7	MVCFlexPre_Left_total - MVCFlexPost_Left_total	1.51667	2.07342	.65567	.03343	2.99990	2.313	9	.046
Pair 8	MVCExtPre_Left_total - MVCExtPost_Left_total	1.30000	1.68288	.53217	.09614	2.50386	2.443	9	.037

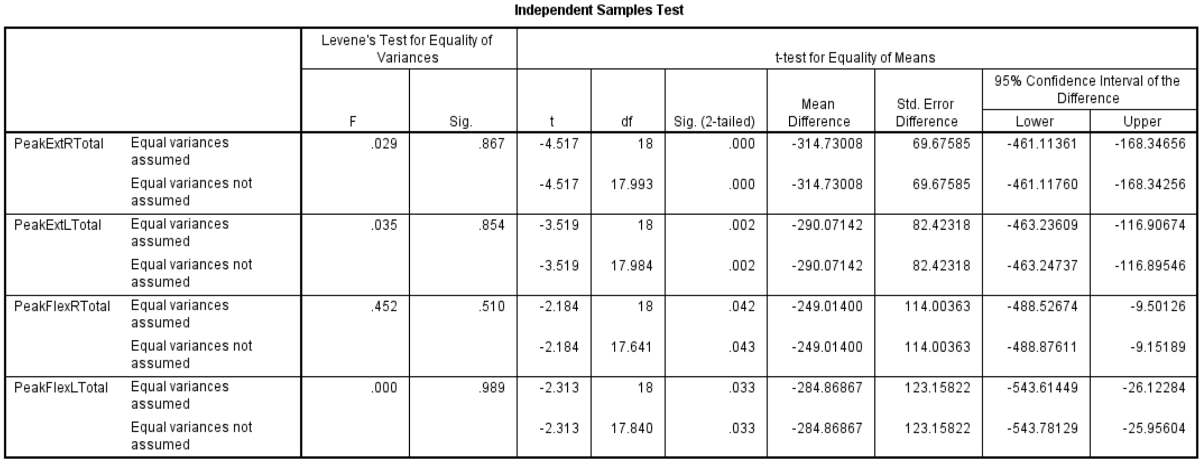
a. Group = 2.00

16. Young vs. Older on Pre or Post

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MaxVelExtPre_Right_total	Equal variances assumed	.679	.421	-.576	18	.572	-87.48333	151.85972	-406.52876	231.56209
	Equal variances not assumed			-.576	16.346	.572	-87.48333	151.85972	-408.85827	233.89160
MaxVelExtPost_Right_total	Equal variances assumed	3.628	.073	-.360	18	.723	-47.40000	131.72710	-324.14837	229.34837
	Equal variances not assumed			-.360	16.017	.724	-47.40000	131.72710	-326.62432	231.82432
MaxVelFlexPre_Right_total	Equal variances assumed	.003	.960	2.573	18	.019	223.20000	86.74950	40.94606	405.45394
	Equal variances not assumed			2.573	17.871	.019	223.20000	86.74950	40.85201	405.54799
MaxVelFlexPost_Right_total	Equal variances assumed	.571	.460	2.793	18	.012	240.81667	86.20970	59.69681	421.93652
	Equal variances not assumed			2.793	17.737	.012	240.81667	86.20970	59.50447	422.12886
MaxVelExtPre_Left_total	Equal variances assumed	.764	.394	-1.848	18	.081	-198.16667	107.22091	-423.42943	27.09610
	Equal variances not assumed			-1.848	16.258	.083	-198.16667	107.22091	-425.17180	28.83847
MaxVelExtPost_Left_total	Equal variances assumed	1.686	.211	-1.559	18	.136	-158.38333	101.61072	-371.85953	55.09286
	Equal variances not assumed			-1.559	13.907	.142	-158.38333	101.61072	-376.45284	59.68617
MaxVelFlexPre_Left_total	Equal variances assumed	.535	.474	.727	18	.477	102.98333	141.74858	-194.81938	400.78605
	Equal variances not assumed			.727	17.451	.477	102.98333	141.74858	-195.49209	401.45876
MaxVelFlexPost_Left_total	Equal variances assumed	.805	.381	.103	18	.919	15.73333	152.27619	-304.18707	335.65374
	Equal variances not assumed			.103	17.675	.919	15.73333	152.27619	-304.60894	336.07561
MVCFlexPre_Right_total	Equal variances assumed	.156	.697	-2.137	18	.047	-6.15000	2.87821	-12.19690	-.10310
	Equal variances not assumed			-2.137	16.883	.048	-6.15000	2.87821	-12.22571	-.07429
MVCExtPre_Right_total	Equal variances assumed	2.717	.117	-1.714	18	.104	-2.61667	1.52693	-5.82463	.59129
	Equal variances not assumed			-1.714	13.122	.110	-2.61667	1.52693	-5.91229	.67896
MVCFlexPre_Left_total	Equal variances assumed	.066	.801	-1.253	18	.226	-3.43333	2.73942	-9.18865	2.32198
	Equal variances not assumed			-1.253	17.278	.227	-3.43333	2.73942	-9.20593	2.33927
MVCExtPre_Left_total	Equal variances assumed	.148	.705	-1.612	18	.124	-2.30000	1.42677	-5.29754	.69754
	Equal variances not assumed			-1.612	17.524	.125	-2.30000	1.42677	-5.30339	.70339
MVCFlexPost_Right_total	Equal variances assumed	.225	.641	-1.175	18	.255	-3.61667	3.07692	-10.08104	2.84770
	Equal variances not assumed			-1.175	17.929	.255	-3.61667	3.07692	-10.08288	2.84955
MVCExtPost_Right_total	Equal variances assumed	2.733	.116	-1.473	18	.158	-1.93333	1.31257	-4.69094	.82427
	Equal variances not assumed			-1.473	14.122	.163	-1.93333	1.31257	-4.74624	.87957
MVCFlexPost_Left_total	Equal variances assumed	.507	.486	-.634	18	.534	-1.78333	2.81432	-7.69600	4.12934
	Equal variances not assumed			-.634	17.851	.534	-1.78333	2.81432	-7.69954	4.13287
MVCExtPost_Left_total	Equal variances assumed	.021	.886	-.926	18	.367	-1.26667	1.36829	-4.14134	1.60801
	Equal variances not assumed			-.926	18.000	.367	-1.26667	1.36829	-4.14134	1.60801

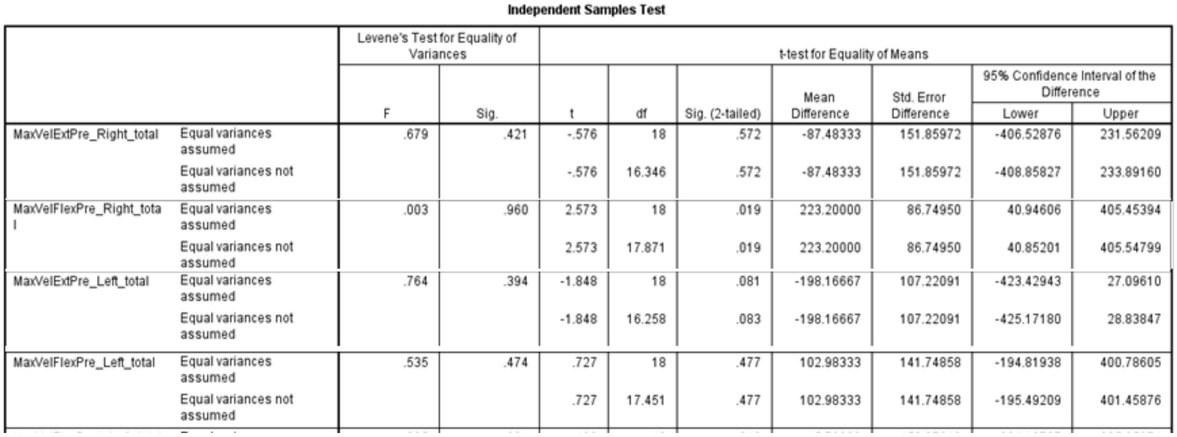
17. Peak Velocity in the first one second



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PeakExtRTotal	Equal variances assumed	.029	.867	-4.517	18	.000	-314.73008	69.67585	-461.11361	-168.34656
	Equal variances not assumed			-4.517	17.993	.000	-314.73008	69.67585	-461.11760	-168.34256
PeakExtLTotal	Equal variances assumed	.035	.854	-3.519	18	.002	-290.07142	82.42318	-463.23609	-116.90674
	Equal variances not assumed			-3.519	17.984	.002	-290.07142	82.42318	-463.24737	-116.89546
PeakFlexRTotal	Equal variances assumed	.452	.510	-2.184	18	.042	-249.01400	114.00363	-488.52674	-9.50126
	Equal variances not assumed			-2.184	17.641	.043	-249.01400	114.00363	-488.87611	-9.15189
PeakFlexLTotal	Equal variances assumed	.000	.989	-2.313	18	.033	-284.86867	123.15822	-543.61449	-26.12284
	Equal variances not assumed			-2.313	17.840	.033	-284.86867	123.15822	-543.78129	-25.95604

18. Maximal Velocity Pre-Task



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MaxVelExtPre_Right_total	Equal variances assumed	.679	.421	-.576	18	.572	-87.48333	151.85972	-406.52876	231.56209
	Equal variances not assumed			-.576	16.346	.572	-87.48333	151.85972	-408.85827	233.89160
MaxVelFlexPre_Right_total	Equal variances assumed	.003	.960	2.573	18	.019	223.20000	86.74950	40.94606	405.45394
	Equal variances not assumed			2.573	17.871	.019	223.20000	86.74950	40.85201	405.54799
MaxVelExtPre_Left_total	Equal variances assumed	.764	.394	-1.848	18	.081	-198.16667	107.22091	-423.42943	27.09610
	Equal variances not assumed			-1.848	16.258	.083	-198.16667	107.22091	-425.17180	28.83847
MaxVelFlexPre_Left_total	Equal variances assumed	.535	.474	.727	18	.477	102.98333	141.74858	-194.81938	400.78605
	Equal variances not assumed			.727	17.451	.477	102.98333	141.74858	-195.49209	401.45876