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EFFECTS OF A SHORT-TERM, HIGH INTENSITY PLYOMETRIC TRAINING REGIMEN ON POSTURAL CONTROL OF YOUNG ADULTS

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SUMMARy

Introduction
Plyometric exercises (such as jumping and hopping) are used by individuals involved in dynamic sports (athletes) to either enhance athletic performance or for rehabilitation. Short-term plyometric training has been shown to positively impact postural control and muscle power in athletes. There have been no studies which investigated this training in non-athletic individuals or considered postural stability changes as a result of this training. Positive changes in lower limb muscle power and therefore postural control, can be immensely beneficial to individuals recovering from injuries or individuals with impaired standing balance due to neurological disorders.

Aim
This study investigated a short-term (10 week), high intensity, bi-lateral plyometric training regime on ten healthy young adults to observe, analyze and characterize their motor control and postural stability. Measurements were taken twice per session: (i) pre-exercise and (ii) post-exercise. The participants' center of pressure (CoP) recordings were carried out using a force plate, and their muscle activity was recorded using six electromyography (EMG) sensors placed on the right and left muscle bellies of the vastus lateralis (VL),

EFEKTY KRÓTKIEGO I INTENSYWNEGO TRENINGU NA KONTROLĘ POSTAWY U MŁODYCH LUDZI

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STRESZCZENIE

Wstęp
Intensywne ćwiczenia ruchowe (takie jak skakanie w miejscu) są bardzo często stosowane przez sportowców w celu poprawy kondycji fizycznej lub rehabilitacji. Wykazano, że krótkoterminowe treningi ruchowe (skakanie w miejscu) pozytywnie wpływają na kontrolę postawy i siłę mięśni u sportowców. Nie przeprowadzono jednak takich badań u osób nie będących sportowcami, ani też nie uwzględniono zmian stabilności postawy w wyniku tych ćwiczeń. Pozytywne zmiany w sile mięśniowej kończyn dolnych, a zatem i kontroli postawy, mogą być niezwykle korzystne dla osób rehabilitowanych z powodu urazów lub osób z zaburzoną równowagą z powodu zaburzeń neurologicznych.

Cel
W przedstawionej pracy zbadano krótkookresowy (10-tygodniowy), o wysokiej intensywności, równo obciążający obie kończyny, system treningowy (2 razy w tygodniu intensywne skakanie w miejscu przez 30 sekund, z przerwa 1–2 minuty, z 4-krotnym powtórzeniem ćwiczeń w ciągu jednej sesji) u dziesięciu zdrowych i młodych dorosłych (w wieku 20,1 1,4 lat) zaproszonych do badań. Przeprowadzono analizę stabilności postawy i kontrolę motoryczną uczestników eksperymentu. Pomiary wykonywano dwa razy w ciągu jednej sesji: (i) przed ćwiczeniami

biceps femoris (BF) and lateral gastrocnemius (GL).

i (ii) po ćwiczeniach. Zmienne położenia chwilowego środka reakcji (CoP) uczestników wykonano za pomocą AMTI AccuSway (Watertown, MA) platformy rejestrującej 3 składniki reakcji siłowej (w trzech kierunkach X, y, Z) i 3 składniki reakcji momentu (w trzech kierunkach X,y, Z), w funkcji czasu. Aktywność mięśniową kończyn dolnych zarejestrowano za pomocą sześciu bezprzewodowych czujników elektromiograficznych (EMG, Trigno Delsys, Natick, MA) umieszczonych na mięśniach prawej i lewej kończyny: vastus lateralis (VL), biceps femoris (BF) i lateral gastrocnemius (GL).

Results and conclusions

The results of this study indicate that plyometric training consisting of high impact bi-lateral exercises induced major improvements in lower extremity power and postural stability. There were significant changes in most CoP measures and EMG-EMG coherence. Therefore, we can conclude that short-term, high intensity plyometric training should be applied to impaired standing balance, and possibly included in rehabilitation programs to improve their mobility and quality of life.

Wyniki i wnioski Wyniki przeprowadzonych badań wskazują, że proponowany trening, intensywne skakanie w miejscu indywidualnie dostosowane do możliwości fizycznych uczestnika, wywołał istotną poprawę stabilności postawy i sił generowanych w kończynach dolnych. Zarejestrowano znaczące zmiany położenia chwilowego środka reakcji (CoP) i spójności EMG-EMG.trening o wysokiej intensywności dostosowany indywidualnie do możliwości ruchowych pacjenta powinien być stosowany do poprawy zaburzeń równowagi ciała i może być włączony do programów rehabilitacyjnych w celu poprawy mobilności i jakości życia pacjentów.

Keywords: plyometric training, posture, rehabilitation, balance, stability

Słowa kluczowe: krótkometryczny trening, postawa, rehabilitacja, balans, stabilność

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Introduction

This project investigates a short-term, high intensity, bilateral plyometric training regimen on healthy, young adults to observe and analyze changes in their performance, motor control and postural stability over time. The results of this study can be used and applied to individuals with impaired standing balance due to neurological disorders to improve their quality of life.

Human upright (vertical) posture, from a mechanical perspective, is regarded as an unstable system which requires various control mechanisms to maintain the center of gravity (CoG) and the center of pressure (CoP) inside the base of support (Suzuki *et al.* 2012). The maintenance of CoG and CoP together, is postural control. To stand without any support is a fundamental skill for independent mobility (Suzuki *et al.* 2012) (García-Massó *et al.* 2016). It was postulated by Bernstein (1967), that the central nervous system (CNS) also plays a vital role in simplifying these redundant degrees of freedom by activating multiple muscle synergies (Shumway-Cook and Woollacott, 2012) (García-Massó *et al.* 2016). Human postural control, although seems simple, is a complex skill which relies on the integration of sensory information from the somatosensory, visual and vestibular systems (Goh *et al.* 2017). These individual systems work in tandem to maintain postural control, and a number of studies have been conducted to confirm the involvement of cortical activity in postural control (Peterka, 2003) (Shumway-Cook and Woollacott, 2012) (Goh *et al.* 2017).

It has been suggested that changes in cognitive function and attention can alter postural stability, and especially affects individuals with movement disorders. These disorders are caused by damage to the motor areas of the brain (Jacobs *et al.* 2015). Cerebral Palsy (CP) is a broad term that is used to describe a group of permanent disorders that impair control of movement, posture and motor function due to damage (non-progressive lesion) in the developing brain (Ajami and Maghsoudlorad, 2016) (Ballester-Plané *et al.* 2016). CP is a prevailing cause of physical disability in children. The incidence of CP according to the United Cerebral Palsy Association (Ucp.org, 2016) is approximately 10.000 infants per year in the USA. Studies have been conducted to observe individuals with CP over time as they progress from childhood into adulthood. As time progresses, individuals find it harder to maintain balance due to factors such as increased pain and loss of mobility (Murphy *et al.* 2008). It was also observed that most of these individuals developed musculoskeletal problems early on, which goes to suggest that abnormal biomechanical forces and immobility led to the excessive physical stress and strain, which ultimately resulted in early joint degeneration (Slaboda *et al.* 2013). This strongly suggests that the prevention or rather, mitigation of these complications could have a significant impact on maintaining function and mobility throughout the lifespan of this population – and therefore the survival of this population.

Multiple studies investigating paradoxical muscle movement during postural control (Masani *et al.* 2003) (Peterka, 2003) (Suzuki *et al.* 2004) (Loram *et al.* 2007) (Asai *et al.* 2009) (Gawthrop *et al.* 2011) (Günther *et al.* 2011) (Shumway-Cook and Woollacott, 2012) (García-Massó *et al.* 2016) (Goh *et al.* 2017) observe that body instability cannot be characterized and stabilized by intrinsic ankle stiffness alone and thus requires a modulation of muscle activity to maintain balance. It supports the idea (Shumway-Cook and Woollacott, 2012) that contractile displacement is mechanically decoupled from bodily sway, implying that the stretch reflex mechanisms mediated in the lower limbs are required to successfully modulate muscle activity to maintain balance (Suzuki *et al.* 2012). A way to quantify neuromuscular control is through measures of CoP and postural sway (Gimmon *et al.* 2011). An increase in postural sway might indicate impairment of postural control – which results in functional postural instability (Gimmon *et al.* 2011) (Shumway-Cook and Woollacott, 2012).

Plyometric exercise or training is popular amongst individuals involved in dynamic sports, and is usually used to improve athletic performance (Myer, 2005) (Chmielewski *et al.* 2006) (Váczi *et al.* 2013) (Kim and Park, 2016). It involves exercises such as jumping, hopping and skipping (Váczi, 2013). The identifying feature of plyometric training is the lengthening of the muscle-tendon unit, which is followed directly by shortening (stretch-shortening cycle) (Winter *et al.* 1996). These exercises are described as biphasic – which means they consist of eccentric and concentric muscle action phases (Winter *et al.* 1996). Besides being able to improve athletic function, more recently, these exercises are being used in the rehabilitation of injured athletes to help them return to their sport as safe and as fast as possible (Winter *et al.* 1996).

Till date, there have been no published studies investigating short-term, high intensity plyometric training regimens on healthy young adults. The few high-intensity studies (Winter *et al.* 1996) (Váczi, 2013) involved professional athletes.

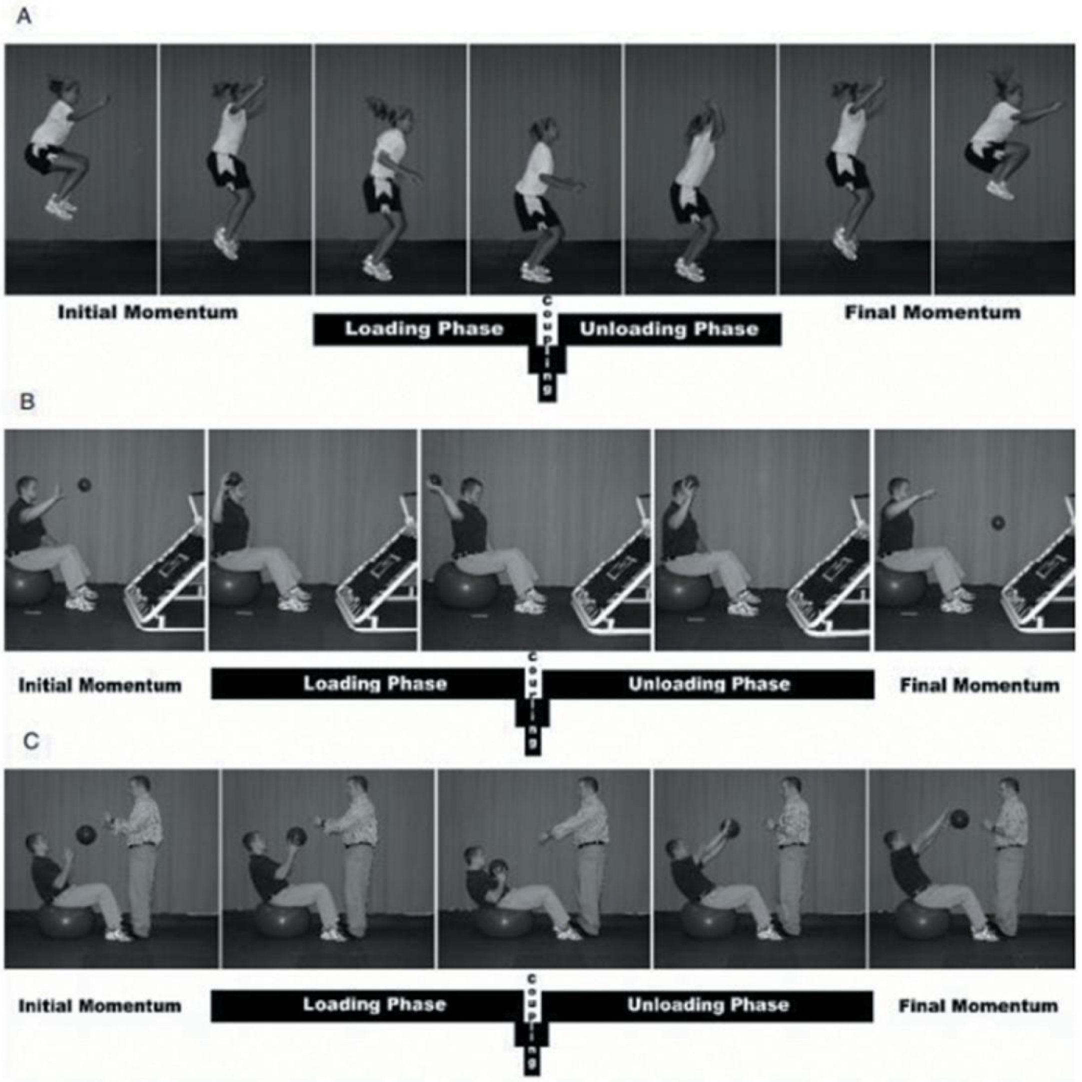

Figure 1: Phases of Plyometric Training Activity. Reprinted from 'Plyometric Exercise in the Rehabilitation of Athletes: Physiological Responses and Clinical Application', Journal of Orthopaedic & Sports Physical Therapy, vol. 36, no. 5, pp. 308–319, 2006, by T. Chmielewski *et al.*, 'Journal of Orthopaedic & Sports Physical Therapy, vol. 36, no. 5, pp. 308–319, 2006. (A) Lower Extremity Plyometric Exercise(B) Upper Extremity Plyometric Exercise(C)Trunk PlyometricExercise.

Aim The first specific aim is to relate the observed changes in the biomechanical measures (dynamic loading parameters) to postural stability. A reduction in the CoP parameters of velocity (ms^{-1}), 95% Ellipse Area (m^2) and Medio-lateral (ML) and anterior-posterior (AP) sway (m) are hypothesized. A reduction in these measures indicates improved balance, as the dynamic loading parameters that are applied to maintain postural control are decreased.

The second specific aim is to determine the effect of this training in the lower limb muscle activity for the postural control task over time by evaluating the gross innervation input of synergistic (each) muscle pairs. The mean Electromyography (EMG) root-mean-square (RMS) comparison between muscle groups assesses the gross innervation input of select muscles during both testing conditions (before and after the training). As the study progresses, the mean EMG RMS signal for synergistic muscle pairs (right and left muscle bellies of the vastus lateralis (VL), biceps femoris (BF) and lateral gastrocnemius (GL) is expected to decrease. These muscles were chosen as they are known to have the largest impact on postural control, and do not require additional filtering against cardiac artifacts (Jacobs *et al.* 2015). A reduction in this measure indicates that less power is exerted by each muscle pair to maintain postural stance, which emphasizes improved balance.

The last specific aim is to perform coherence analysis to characterize lower limb muscle patterns as the study progresses. EMG-EMG coherence estimations are used to analyze the coordination between synergistic pairs of muscles by analyzing EMG signals in the frequency domain and analyzing their commonalities. An overall increase in coherence of muscle pairs over time is expected as the task becomes practiced and involuntary.

Materials and methods

This study focuses solely on the biomechanical aspects of postural stability and balance control. The dynamic loading measures were recorded using one AMTI AccuSway Force Platform (AMTI AccuSway, Watertown, MA), and the muscle activity measures were recorded using six wireless EMG sensors (Trigno, Delsys Inc. Natick, MA). EEG measures were taken using the Brain Vision actiCHamp system (Brain Products, GmbH, Munich, Germany). To be able to interface to three different sensor systems and cater to their specifications, an Arduino Uno (Arduino.cc, 2017) microcontroller was used to trigger the three systems to record data simultaneously. The software used to analyze the data after extraction from the program was MATLAB R2015a (Mathworks Inc., Natick, MA).

Ten healthy, young participants (Age: 20.1 1.4 years) were divided into three groups based on their gender, body mass and height. Each participant underwent 30 experimental visits (30 times a week for 10 weeks) in total, where each session lasted approximately half an hour. Participants were required to take one day of rest, but no more than four days of rest between experimental visits. The protocol described below explains the entire procedure for each session. The experiment (recordings) itself consisted of two test sessions (pre and post-exercise) and a plyometric training intervention. This regimen was designed based on past literature:

1. Quiet standing on the force platform for 90 seconds while ground reaction forces and EMG measures are recorded.
    a. There are six EMG sensors, which were placed on the left and right muscle bellies of the participants' vastus lateralis (VL), biceps femoris (BF) and lateral gastrocnemius (GL) by the researcher.
2. Warming up the body for 5-minutes before undergoing the plyometric training regimen.
    a. All the sensors are removed from the participant, and not included again until step #8.
    b. Warm-up includes dynamic ankle, knee, and hip stretches; stationary stepping; and shallow, stationary hops.
3. Stationary hopping (i.e. on the ground, in place) at a self-selected rate for 2-minutes.
4. Rest for 2 to 3 minutes.
5. Stationary hopping for 30 seconds at the fastest voluntary speed and height possible for the participant (greatest or maximum effort), for four sets with one-minute of rest in between sets.

6. Rest for 2 to 3 minutes.
7. Cool down the body for 3–5 minutes consisting of 3 sets of 10 seconds submaximal hopping, followed by slow walking or stationary stepping.
8. Quiet standing on the force platform for 90 seconds while EMG (and EEG) measures are taken.

During the plyometric training sessions (i.e. NOT when recordings were taken), work-out music was played to keep the participants motivated always. Continuous verbal encouragement and feedback were also given by the researcher(s). It is also to be noted that for step #5, a two-minute rest was given between each set for the first 4 weeks. It was then stepped up to 1.5 minutes in week 5 and finally, one minute in week 6. This gradual progression (Chmielewski, 2006) of recovery time was carried out to ensure that the participants had enough rest for proper execution of the exercise. As the training became more practiced and voluntary, the recovery time was reduced based on observation and mutual consent.

The vertical jump performance test was executed bi-weekly throughout the study. Participants were standing next to a wall, while remaining flat-footed to record standing height. The vertical jump test was performed using the tape method (similar to the chalk method) (Váczi, 2013), where each participant was given a piece of colored tape placed on their dominant hand. They then had to jump bilaterally (using proper form as instructed) and slap the tape as high as they possibly can on the wall. Each participant had three trials, with a few minutes of rest in between each trial. The maximum vertical jump height from each session was recorded for further analysis.

Results

The CoP signals were sampled at 100 Hz and low-pass filtered using a second order Butterworth IIR filter with a cut off frequency of 15 Hz (as suggested in previous literature (García-Massó *et al.* 2016). The first 10 seconds and the last 10 seconds were discarded before computation of any variables. In the time domain, the balance variables/dynamic loading parameters which were computed were: CoP velocity (ms-1), CoP 95% Ellipse Area (m2) and displacement (m) in the medio-lateral (ML) and anterior-posterior (AP) directions. These parameters were calculated for every training session (pre and post-exercise). The CoP signals were also normalized to each participant's weight and height.

The CoP velocity decreased across all groups of participants as hypothesized. Overall, Group 2 participants showed the most significant reduction. The percentage difference in the velocity was calculated and tabulated for each participant in Figure 2. Please note that for the proceeding graphs, participants 1 and 2 are part of group 1, participants 3–6 are in group 2, and participants 7–10 are in group 3.

The CoP 95% Ellipse Area also decreased across all groups of participants over time, and can be seen in Figure 3. Once again, overall, Group 2 showed the most significant reductions in the average CoP 95% Ellipse Area.

Postural sway in the medio-lateral (ML) and anterior-posterior (AP) directions were expected to reduce overall, as well. However, it reduced for certain individuals and increased for others. While there were no significant reductions in postural sway, overall the displacement across all participants stabilized after week 5.

EMG signals were sampled at 1926 Hz and pre-processed to delete background noise and interference. First, a notch filter was applied to remove the 60 Hz power line component and its secondary harmonics. This was followed by a second-order low pass filter of 100 Hz. The presence of electrocardiogram signals in EMG could increase the coherence between core muscles (García-Massó *et al.* 2016). Independent component analysis was not needed to be taken into consideration as

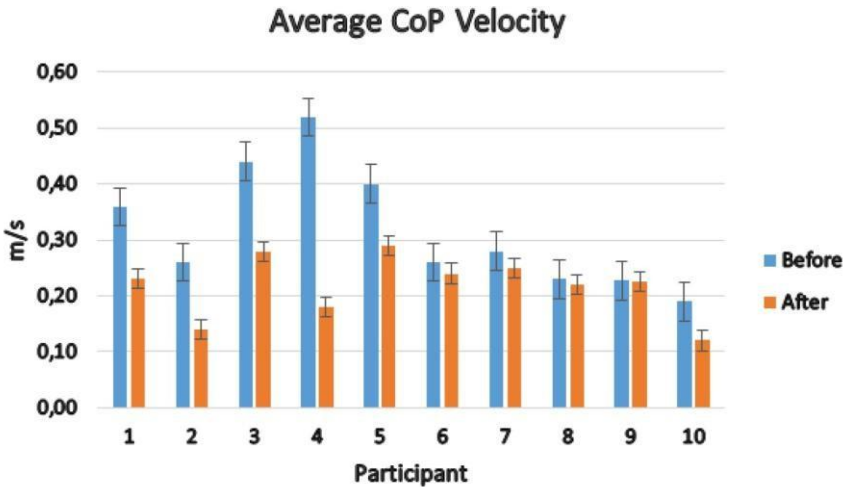

Figure 2: Averagecenter of pressurevelocity acrossall participants.

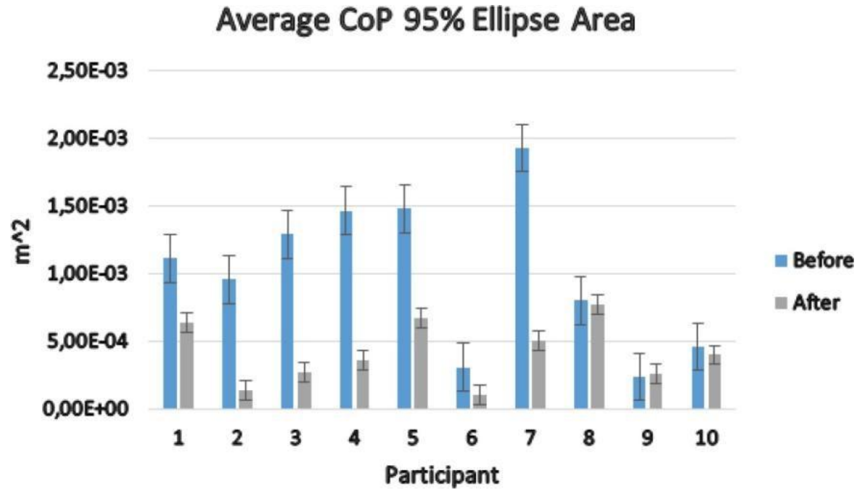

Figure 3: Averagecenter of pressure95%ellipse areaacrossall participants.

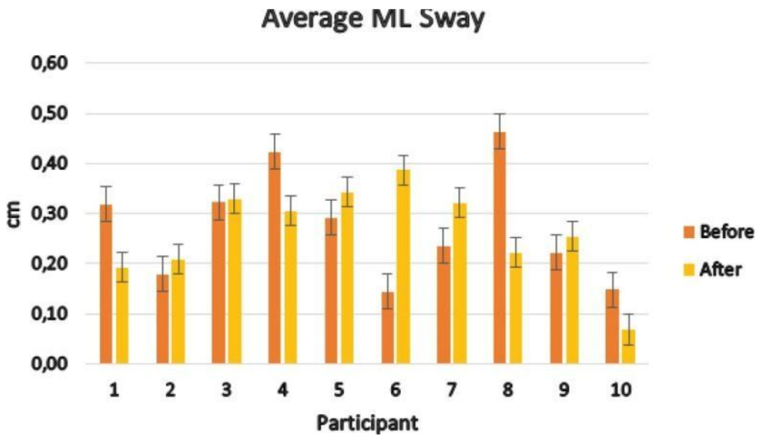

Figure 4: AverageML swayacrossall participants.

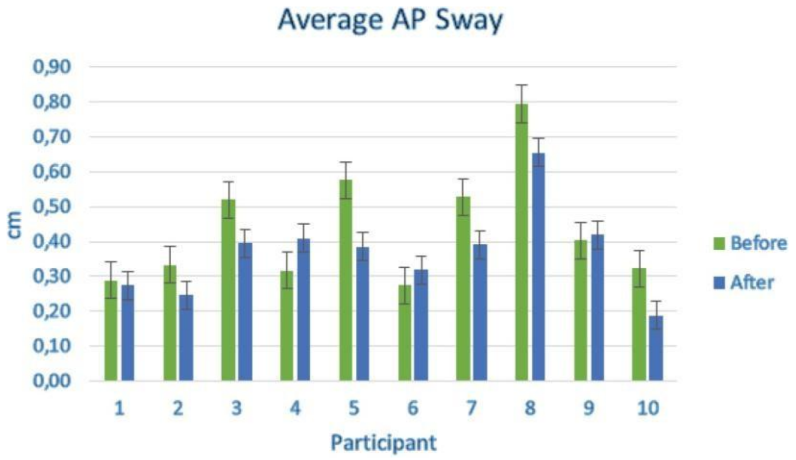

Figure 5: Average AP sway across all participants.

the muscle bellies chosen (VL, BF, GL) are known to not need any additional filtering against electrocardiogram interference (Jacobs *et al.* 2015) (García-Massó *et al.* 2016). The first 10 seconds and the last 10 seconds were discarded in order to use the same time period as the CoP signals.

The mean value of the root-mean-square (RMS) EMG signal was then computed as a variable of the magnitude for muscle activation for each trial. The EMG RMS calculation is considered to provide the most insight on the amplitude of the EMG signal as it gives a measure of the power of the signal.

The EMG RMS was hypothesized to decrease as the study progressed. This is mostly seen across all groups (and individual) of participants. Figure 6 below shows a random participant's data from each of the three groups of participants.

Coherence analysis was carried out in accordance with past literature (Grosse *et al.* 2004) (Jacobs, 2015) (García-Massó *et al.* 2016). In the frequency domain, the EMG signals were analyzed by estimating the EMG-EMG coherence of synergistic muscle pairs (single-pair estimations). Pairs of muscles are defined as the comparison between (1) left and right VL; (2) left and right BF; (3) and left and right GL. The single pair coherence estimations were performed using the Welch method (García-Massó *et al.* 2016) (an extension of the Pearson's correlation coefficient):

$$(\,) =^{2} \frac{() = \;{}^{2}\overline{\qquad\qquad\qquad}^{2} \quad ()\;\;()}{()\,()} \qquad [Eq.1]$$

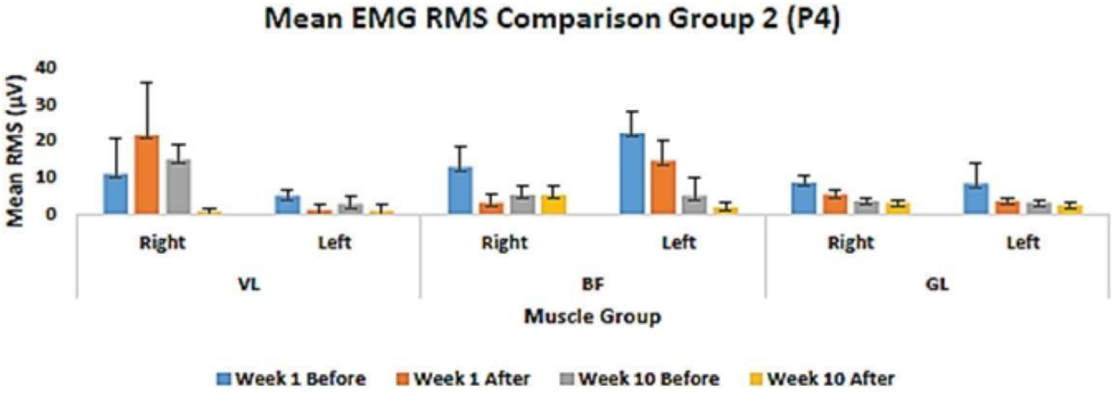

Figure 6: EMG RMS for a random participant.

Where $R_{xy}(\lambda)$ is the intermuscular coherence, $f_{xy}(\lambda)$ is the cross-spectrum between both signals, $f_{xx}(\lambda)$ is the auto-spectrum of the first signal and $f_{yy}(\lambda)$ is the auto-spectrum of the second signal.

The estimated coherence using Welch's periodogram (García-Massó *et al.* 2016) method was obtained with the assistance of in-built MATLAB functions. The coherence spectra are determined using the fast Fourier transform (FFT). The spectra derived using the FFT approach are defined pointwise, and the difference in frequency between two adjacent points is given by the sampling rate divided by the FFT window size (Grosse, 2004). A non-overlapping Hamming window of 512 points (number of samples/2 = 417 which closest power of 2 is 512) and a frequency range from 0–55 Hz was analyzed.

In accordance with previous literature (García-Massó *et al.* 2016), the statistical significance for single pair coherence estimations was computed to obtain a threshold which was 95% confidence interval per muscle pair. The equation used to calculate this 95% confidence threshold is:

$$\overline{} \quad - \quad \sqrt{} \qquad [Eq.2]$$

Where ‘ $\overline{}$’ is the mean of the sample, ‘sd’ is the standard deviation of the sample, ‘n’ is the number of samples, and ‘z’ is the t-value for the one-sided confidence limit at 95% ($p < 0.05$).

It was hypothesized that higher amplitudes of muscle activity is expected to be observed in the lower frequency range (0–10 Hz) and an overall increase in coherence over time. The results in Figure 7 show that the coherence did increase across all participants. Most of the increase in coherence was in the lower leg (GL) as opposed to the upper leg (VL, BF).

For the vertical jump test, performance (which was recorded bi-weekly) improved overall across all groups of participants. This can be seen in Figure 6 below.

Discussion

In this study, it was hypothesized that a short-term (10 week), high intensity, bilateral plyometric regimen will change and improve various dynamic measures in young adults. This was the first study to investigate a high intensity plyometric training regimen in non-athletic young adults (i.e. not professional athletes).

When assessing postural stability measures (dynamic loading parameters), the CoP velocity and CoP 95% Ellipse Area (EA) decreased across all participants, as expected. The percentage range of decrease for the CoP variables ranged from a 0.5% decrease to a 66% decrease for certain individuals. This is an extremely large range of values that were obtained. This decrease could be attributed to varying time frames and intensities of muscle reorganization for each participant (Váczi, 2013) (García-Massó *et al.* 2016). It was observed that Group 3 (male) participants had the lowest change in CoP velocity. This participant group were on the higher end of the body mass and height scale.

All participants were instructed and verbally motivated to ensure that maximal intensity was being exerted throughout the training regimen. Intensity and frequency are inversely proportional often (Váczi, 2013), in training programs. These two factors in this study remained constant throughout and were not changed. The frequency of the jumps was determined by each individual, depending on their comfort and capabilities. During the training regimen, the participants were limited to the ceiling. It was evident that especially group 3 participants could, in fact, jump to a higher level with maximal effort. This could be an attributing factor to this large difference in variation between the different participant groups, as group 3 participants were actually executing the exercise at a sub-maximal level. They were instructed to however compensate this by increasing the frequency of their jumps. A similar trend was also observed for the CoP 95% Ellipse Area, where

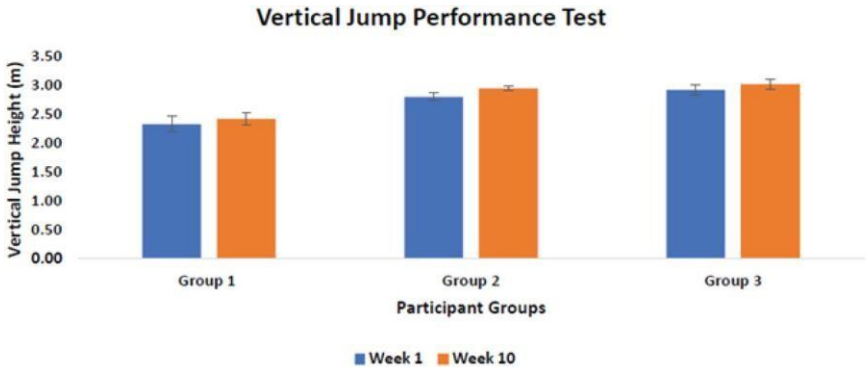

Figure7: Average vertical jump height for groups 1–3 before and after the plyometric regimen.

group 3 participants improved, but significantly less than their counterparts.

During the study, the recovery time between the four repetitions of the plyometric training exercise was shortened as the study progressed. The participants were given a two-minute recovery period in between the sets. This reduced to one and a half minutes in week 4 and 5 and finally, to one minute rest from week 6 onward. As suggested by earlier studies (Chmielewski, 2006), this was done to ensure that the plyometric activity was first introduced to ensure neuromuscular control and endurance before increasing the frequency and/or decreasing the recovery period. As seen consistently throughout the results, the CoP velocity and CoP 95% EA increased during this period of time, as expected. This could be attributed to compensation of the lower limbs to ensure that sufficient muscle force is available for the optimal performance of these exercises (Chmielewski, 2006).

The volume, or total work performed (number of sets/repetitions) also remained constant throughout the study. The number of repetitions remained constant throughout the study, so it was evident that decreasing the recovery time in between repetitions did have an impact on the performance by increasing the CoP velocity and CoP 95% Ellipse Area.

In terms of postural sway, there were no significant differences observed. From previous work (Myer, 2005) (Chmielewski *et al.* 2006) (Martyn-St James and Carroll, 2009) (Shumway-Cook and Woollacott, 2012) (Váczi *et al.* 2013) (Zhao *et al.* 2014) (García-Massó *et al.* 2016) (Kim and Park, 2016), it is seen that it takes (on average) four weeks for a task to become practiced and involuntary. This could be a plausible explanation as to why the postural sway stabilized midway through the study.

As expected, the EMG RMS values significantly decreased across all groups of participants, indicating that over time, they required less power by each muscle to achieve the same postural stance. The decrease in muscle activation (muscle force production) indicates improved postural stability as less force is exerted by each muscle to maintain bipedal stance.

Inter-muscle coordination was evaluated by analyzing EMG-EMG coherence of synergistic pairs of muscles over time. Consistent with previous studies (Grosse, 2002) (Grosse *et al.* 2004) (Jacobs *et al.* 2015) (García-Massó *et al.* 2016), it is observed that significant coherence was observed in the lower frequency range (0–10 Hz) for the postural control task. The coherence also changed and (mostly) increased across all participants. This is indicative of increased or better inter-muscular coordination as the study progressed, which emphasizes improved standing balance. Similar to the mean EMG RMS analysis, the larger difference was seen in the GL muscle compared to the VL and BF muscles. This further validates that the lower leg contributes more to postural stability compared to the upper leg.

With regards to the vertical jump performance test, a percentage change of 4–5% indicates significant changes in lower leg power have occurred, which further validates the benefits of maximal intensity plyometric training. Previous studies involving professional athletes showed a 4% improvement (Váczi, 2013) in six weeks. Considering this population was non-athletes, this is regarded as a major improvement. As previously suggested (Váczi, 2013), this improved intermuscular coordination, possible increased neural drive, and changes in the muscle-tendon complex have occurred. These neurophysiological changes together, suggest the improved ability to store and release elastic energy during the stretch-shortening cycle.

Of course there were some limitations that should be taken into account, such as individual variations in body segment position changes or the population sample size. The population demographics in this study involved more male participants compared to female participants. It would have been more conclusive if there was a larger demographic observed. Another limitation was that the participants were restricted to the ceiling in terms of how high they could jump, which especially affected the taller group of participants (group 3). One more limitation was that there was only one force platform used. Evaluating inter-limb coordination would be more effective if there were two force platforms used so that the CoP and ground reaction forces exerted from each limb would be more accurate, rather than analyzing the overall (average) CoP measures. Another limiting factor was the number of EMG sensors. This study was limited to six sensors, so the muscles had to be chosen strategically. Another very important muscle in postural control that was not measured is the tibialis anterior (TA), which would have been interesting to measure if there had been enough sensors to accommodate.

It can be seen that this study's plyometric training regimen has had a positive effect on the lower limb strength, muscle activation and postural stabilities of the participants involved. Practically, it can be used as an alternative approach in improving and treating impaired standing balance. This training could potentially be used to not only help individuals enhance athletic performance and recover from injury, but also to individuals with neuromuscular disorders to improve their strength and mobility. A regular, well-designed, high intensity plyometric training regimen could potentially be incorporated into rehabilitation programs as an alternative to improve impaired standing balance, and subsequently improve quality of life. A very under-represented and under-researched population is those suffering from Cerebral Palsy (CP), and specifically adults with CP. This plyometric training regimen could be extended to a longer period of time to be able to see beneficial and significant results in their performance, motor control and postural stability. Additionally, this study could also be applied to the geriatric population, individuals with Parkinson's disorder (as they are believed to have a depth impairment (Shumway-Cook and Woollacott, 2012)), muscular dystrophy, and/or people recovering from a stroke.

Conclusions

A short-term, high intensity, bilateral plyometric training regimen in young adults showed major improvements in lower limb strength.

The same bilateral plyometric training regimen showed improved intermuscular coherence in the participants.

The above conclusions support the assertion that postural stability was improved as well in the young adults that completed the study.

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