Post-Activation Performance
Enhancement in Sledge Ankle Hops after a 6-seconds maximal Isometric Plantar Flexion

Gabriel Solé
Acknowledgments

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Abstract

Aim
The aim of this study was to investigate the effects of a 6-second maximal voluntary isometric contraction (MVIC) of the plantar-flexors on subsequent ankle hops performed only by plantar flexing at the ankle.

Methods
10 physically active university students were recruited to volunteer in this study. All subjects were free from injury in the right ankle. The tests were performed in a single session, even though this study is a part of a bigger study that involved several visits to GIH. The 6-sec MVIC was performed in an isokinetic dynamometer and the ankle hops were performed in a custom built backwards tilted jumping sledge. Each subject performed two baseline jumps with one minute of rest between them. Right after the baseline, subjects performed the 6-sec MVIC followed by another two jumps at 30 seconds, 90 seconds, 3 minutes, 5 minutes, 8 minutes and 15 minutes after MVIC.

Results
A significant difference was found for peak force at 30 seconds when compared to pre-test 1 (p= 0.020). No significant difference could be found between either pre-test 1 or pre-test 2 at any time frames for average rate of force development, Rate of force development between 0-50 milliseconds, Rate of force development between 0-90 milliseconds, Time in the air and Time to take off.

Conclusion
A 6-sec MVIC of the plantar flexors did not improve isolated plantar flexor jump performance. While such conditioning contractions has previously been shown to temporarily potentiate the contractile properties of the plantar flexors as assessed by a single twitch, such effects may not be readily transferred to functional voluntary tasks.
Sammanfattning

Syftet
Syftet med denna studie var att undersöka effekterna av en 6-sekunders maximal frivillig isometrisk vadmuskel-kontraktion (MVIC) på enbenschopp som endast utförs med vadmusklerna.

Metod
Tio fysiskt aktiva högskolestudenter deltog volontärt i studien. Försökspersonerna var friska och fria från skador i högra fotleden. Testerna utfördes under ett tillfälle men det är bra att veta att denna studie är en del av större undersökning som gjordes genom flera besök på GIH. Den 6-sek MVIC utfördes i en isokinetisk dynamometer och hoppet utfördes i en specialbyggd bakåtlutad hoppslåde. Varje individ utförde två baslinje-hopp med en minuts vila emellan dem. Direkt efter utförde försökspersonerna 6-sek MVIC följt av ytterligare två hopp som kom 30 sekunder, 90 sekunder, 3 minuter, 5 minuter, 8 minuter och 15 minuter efter MVIC.

Resultat
En signifikant skillnad hittades för maxkraft vid 30 sekunder i jämförelse med förprov 1 (p=0,020). Ingen signifikant förändring sågs jämfört med vare sig förprov 1 eller förprov 2 vid någon tidpunkt för genomsnittlig nivå av kraftutveckling, Nivå av kraftutveckling mellan 0-50 millisekunder, Nivå av kraftutveckling mellan 0-90 millisekunder, Tiden i luften och Tid till foten lämnar underlaget.

Slutsats
Denna studie visar på att en 6-sek vadmuskel-MVIC förbättrar inte isolerad hoppförmåga i vaderna. Trots att denna typ av kontraktion har visat sig potentiella vadmusklernas kontraktila egenskaper när du undersöks via en enskild el-inducerad muskel-twitch så verkar inte detta nödvändigtvis överföras till en förbättrad prestation in en funktionell viljemässig uppgift.
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1. Introduction

The contractile history of a muscle will directly influence its volitional or electrically evoked responses. After a muscle activation for example, fatigue will be induced and a decrease in force will be observed. In contrast, the same activation may induce potentiation effects, which will facilitate force production and oppose neuromuscular fatigue. When the potentiation is higher than fatigue, increased neuromuscular performance will occur because of this coexistence (Hodgson, Docherty & Robbins, 2005). This relationship is clearly displayed in the Fig. 1. The previous muscle activation mentioned above is often referred to as conditioning contraction (CC) (Tillin and Bishop 2009), and whenever a CC originates from an electrically evoked contraction the subsequent increase in contractile response is called post tetanic potentiation (PTP). Alternatively, when a CC originates from a voluntary muscle activation, the subsequent contractile response will be denominated post-activation potentiation (PAP) (MacIntosh 2010). A third type of potentiation is the staircase, where the CC are repeated low-frequency electrical stimulations where contractions sequentially increase in amplitude (Blazevich & Babault, 2019), this last one will not be addressed in the current paper.

![Figure 1 – due to copyright reasons, the images are missing in the electronic edition](image)

Hypothetical illustration of the coexistence of potentiation and fatigue, where neuromuscular fatigue obtained from the contractile history will be opposing the potentiation effect. In that scenario, the decrease in force as a consequence of fatigue will be competing with the facilitated volitional force production (Tillin & Bishop, 2009).

1.1 Mechanisms of neuromuscular potentiation

The effect of a previous muscle activation on subsequent force production has already been documented with studies involving human muscles in the early 1900’s (Brown and Tuttle 1926). To quantify the neuromuscular output after a CC, H-reflex and muscle twitch force are the most common measures used in the literature (Enoka, Hutton & Eldred, 1980; Sale, 2002).

The amplitude of the H-reflex reflects the excitability of the motoneuron and the presynaptic inhibition of the afferents. The test is performed using an electric stimulator and an EMG set to record the muscle response. The H-reflex bypasses the muscle spindle, and, therefore, is a valuable tool in assessing performance of monosynaptic reflex sensitivity among multiple subjects (Palmieri, Ingersoll & Hoffman, 2004). The H-reflex usually undergoes a brief period
of depression (10-60s) and a subsequent potentiation of up to 10 minutes after CC. This potentiated phase was described as a form of neural potentiation (PTP) in the past (Trimble & Harp, 1998). The main mechanism behind it has been attributed to a residual elevation in presynaptic Ca2+, causing a corresponding increase in the probability of neurotransmitter release from the presynaptic membrane terminal (Zucker & Regehr, 2002). According to Hodgson, Docherty & Robbins (2005) it could be possible to observe post-activation potentiation (PAP) in the H-Reflex, however it would be necessary to reflect some tetanic electrical stimulation characteristics in the voluntary contraction, therefore, twitch force is more commonly used for this type of assessment.

Twitch force is the measure of a contractile response to a single activating stimulus (electrical pulse) delivered to the motor nerve or directly to the muscle (Enoka, 2008). Twitch potentiation (TP) can occur after a sustained maximal voluntary contraction (MVC) or an evoked tetanic contraction (Babault, Maffiuletti & Pousson, 2008). Metzeger et al. (1989) observed TP in the skinned fibers of mammalian skeletal muscle. And already at that time, the author concluded that the myosin regulatory light chain (RLC) phosphorylation was the modulating factor behind it. In fact, when it comes to PAP, more recent studies in humans have shown that the main mechanism behind it is the enhancement of the activation of the myosin heads through phosphorylation of their RLC (Tillin & Bishop, 2009). According to Szczesna et al., (2002), the reason why phosphorylation of the RLC improves contractile muscle function has to do with its effect of improving Ca2+ sensitivity. Ca2+ plays a major role in muscle activation by binding to troponin C (TnC), which initiates a series of conformational changes within the proteins of the thin filaments and leads to muscle contraction. The same author suggests that although the thin filament proteins Tn and Tm mediate the regulation of skeletal muscle contraction, the role of RLC in these processes cannot be ignored and need to be further explored. An example on how PAP can be measured, and its potential effects are illustrated in

Fig 2. due to copyright reasons, the images are missing in the electronic edition
A baseline twitch evoked contraction in a muscle followed by a 10-second CC. Later, the potentiated twitch can be seen soon after the CC, showing the increased force and shortened time course typical of PAP. (Sale, 2002).

In practical terms, during twitch potentiation (TP), the phosphorylation process will increase the myosin head mobility allowing for the myosin heads to move closer to actin binding sites (Alamo et al., 2008; Brito et al., 2011), increasing the rate of cross-bridge formation and
enhancing rate of force development (RFD) during subsequent maximal efforts. It is important to observe that muscle contractions cannot be improved if the muscle is fully activated (Metzger et al., 1989), because in this case, the maximum number of possible cross-bridge attachments is already fulfilled. Therefore, RFD and peak force can be improved mainly during maximal explosive activities but not in maximal strength actions such as heavy squats.

All the observations mentioned above can be seen in two studies. One from Baudry and Duchateau (2007) where a 6-seconds isometric contraction of the thumb elicited PAP, resulting in a greater rate of force development in a maximal voluntary contraction (MVC) and a second one by Gago et al., (2020), where the authors observed an improved twitch RFD after a 6-seconds maximal voluntary isometric contraction in the plantar flexors. These is clearly displayed in Fig. 3, taken from Macintosh, Robillard & Tomaras (2012), where the authors portray a pair of maximal contractions superimposed. One has a faster rate of force development, like what would be expected with PAP and shows that the contraction terminated earlier. The other has a longer duration, needing more time to achieve the same levels of force, meaning the RFD was smaller.

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Figure 3 - maximal contractions superimposed

Another relevant characteristic of PAP is that it is more pronounced in fast twitch type II muscle fibers (Moore and Stull, 1984). The reason behind it seems to be the lower basal Ca2+ sensitivity of these types of fibers, making them more susceptible to stimuli that improve calcium sensitivity (Metzger and Moss, 1990; Moore and Stull, 1984). Therefore, individuals with a higher rate of type II muscle tend to benefit the most from PAP effects.

Finally, the phosphorylation of the regulatory light chain prevenient of PAP, provides only short-term effects to motor units that were activated during the conditioning contraction and all the effects will dissipate after 5–6 min of inactivity. This means that any enhancement of performance attributed to PAP can only be effective within a short time frame, usually between 1-5 minutes. (Macintosh, Robillard & Tomaras, 2012).
Even though all these observations seem promising, Macintosh, Robillard & Tomaras (2012) warn that potentiation is less evident under high activation frequencies, and more evident at low activation frequencies. Therefore, it becomes difficult to accept that PAP could enhance functional performance. For that reason, if the goal is to bridge a gap between laboratory and field settings, it becomes imperative to evaluate physical performance in functional actions such as jumping, sprinting or lifting, together with twitch contractile forces.

1.2 PAP applied movement studies

Since potentiation effects were first observed, there was a growing interest in how to apply this knowledge into sports performance. As a result, in the last decades many authors have tried to apply several protocols to elicit PAP in a variety of conditioning activities, warm-ups and complex training methods (Tillin & Bishop, 2009; Nibali et al., 2015; Hodgson, Docherty & Robbins, 2005; Cochrane, Firth & Stannard, 2009). Although PAP seems clear in twitch contractile muscle functions, the functional effect of this potentiation is unclear. This is shown in the review written by Zimmerman, MacIntosh & Dal Pupo, (2020) where the authors show that very few studies measured both a potentiated voluntary performance enhancement and a potentiated twitch response using electrical stimulation as part of the same experiment. In their review, some studies reported increases in functional performance when PAP levels were high. However, other studies reported higher functional performance when PAP was not present and also, unchanged or diminished performance when PAP was high. The observations in this literature review indicate that mechanisms behind functional performance are more complex than the mechanisms of PAP and one should not assume that regulatory light chain phosphorylation is the mechanism for such enhanced voluntary performance. Therefore, even though studies with PAP have gained interest in the past few years because of the potential performance enhancements in explosive tasks and the possibility that these could be applied by athletes to improve training efficiency and performance, recent studies have raised awareness of the need to differentiate PAP from performance enhancement of functional movements in more complex scenarios. According to this new approach, post-activation potentiation cannot be used when the electrically evoked twitch properties and physiological measures of PAP are not accessed. In that case the term post-activation performance enhancement (PAPE) should be chosen (Prieske et al., 2020; Blazevich & Babault, 2019).
The main point of stipulating a new term is to understand that not every performance enhancement following a CC should be classified as the traditional mechanistic understanding of PAP, as claimed by Prieske et al., (2020). According to the authors, researchers must take into consideration the following factors to properly classify a CC into PAP or PAPE: (i) research field; (ii) effective conditioning contraction; (iii) verification, (iv) effects, (v) occurrence; (vi) time course.

1.3 PAP vs. PAPE: differences and similarities

In a narrative review, Blazevich & Babault (2019) state that PAP and PAPE share similarities such as: Enhanced contractile force, delay before potentiation, and larger response in type II fibers. However, they differ in many other ways: Early effect (within seconds) observed in PAP versus delayed effect (after minutes) in PAPE; PAPE but not PAP may be strongly influenced by muscle temperature changes and intramuscular fluid accumulation; and there is a possibility that neural mechanisms impact PAPE but not PAP. The authors also question if triggering PAP has important effects on voluntary muscular force production in real life contexts. All the main differences found in the literature between PAP and PAPE are displayed in table 1.
To better identify the mechanisms and classifications related to PAP and PAPE it is important to have a standardized methodology that would allow for more applicable research. In that sense, Boullosa et al. (2020) proposed a new taxonomy as an attempt to address all the limitations of the current state of the art in terms of acute performance enhancement. The authors propose that the enhancement of any muscle performance with simple or complex verification tests could be better taxonomized using another model, which would consider conditioning stimuli, verification tests, and population of athletes as main factors involved in these relationships and subsequent classifications.

In this new proposal, the analysis would be based on models to improve performance on a specific task in a specific population only, independent of the term used.

For example:

1. post-high-intensity plantar flexion, sprint potentiation in well trained runners

2. post-high-intensity squat, jump potentiation in resistance trained males

This could be an interesting solution, since from a field-based perspective, performance enhancement could be higher when analyzed in a condition that somehow mimics the neural and mechanical characteristics of a movement. However, an alternative option is being proposed by this study, where there’s an attempt to identify PAPE in a scenario with three levels of experiments, all in which the data collection happened under the same circumstances. The data used on the three experiments was collected on separate days, with the same subjects and very similar conditions, two of the samples are published in a single article (Gago et al., 2020). In that published paper, it was observed significant enhancements in peak torque and rate of torque development during maximal voluntary plantar flexions performed at a moderate controlled velocity after a 6-seconds maximal voluntary isometric contraction (MVIC). The time frame of this effect matched the more mechanistic sample, where twitch contractile properties of the same plantar flexors were also potentiated using a 6-seconds MVIC, indicating PAP. Now in this third level of analyses, we will study the effects of a 6-seconds MVIC in an explosive task, looking into a more functional task but still isolating the plantar flexors. In this manner, it is possible to analyze variables in a more isolated way and avoid interference from external factors that influence more complex movements. To the authors knowledge, no studies have tried to identify mechanisms of acute performance enhancement in such sequential and
controlled conditions. There is, therefore, a need to bridge the gap between the mechanistic and applied sciences in the field of potentiation.

1.4 Aims and research questions

The aim of this study was to investigate effects of a 6-seconds MVIC of the plantar flexors on subsequent ankle hops performed only by plantar flexing at the ankle. Knowledge of this would aid researchers to design more appropriate methods for future research regarding PAP. Furthermore, practitioners are driven by performance, and the current study can aid in future research looking into diverse warm-up strategies to enhance acute performance.

This study tried to answer the following questions:

1. Does a 6-seconds MVIC improve jump performance at different time points after the CC?
2. Are the effects of PAP large enough to enhance performance on the field?

2. Methods

2.1. Study Design

This study was part of a larger study with a different primary objective which used a quantitative and experimental design to investigate the effects of a 6-second maximal voluntary isometric contraction (MVIC) on Rate of torque development (RTD) and neuromuscular efficiency at different portions of the rising torque curve in maximal voluntary concentric plantar flexions (MVCC) while considering possible tensile shifts of the plantar flexor muscle-tendon unit (MTU) and changes in evoked twitch characteristics. The data selection of the present study was retrieved from raw files from the previous project mentioned above and contemplated the same selection of subjects to investigate the effects of a 6-second MVIC of the plantar flexors in the force qualities of a sledge ankle hop during different time points.
2.1. Subjects
Ten physically active university students participated in the study (2 females and 8 males). All participants were free from previous injury of the right ankle. None of the participants were under 18 years of age. All of the participants were instructed that they would visit the laboratory on several occasions and that they were to continue their personal training regimen but abstain from exercising on the day of the experiment. The details are displayed in table 2.

Table 2 - Subjects descriptives

<table>
<thead>
<tr>
<th>Age (Y)</th>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>25</td>
<td>178</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>5.9</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Data is described as mean ± standard deviation

2.2. Ethics
The study was approved by the regional ethics committee of Stockholm and all procedures adhered to the Declaration of Helsinki. All participants were informed of the objectives of the study and signed an informed consent form.

2.3. Procedure
The data collection for this study took place in one single session. All the data was collected in the biomechanics laboratory at the Swedish School of Sport and Health. Upon arrival and after proper preparations, participants were allowed to voluntarily familiarize with the sledge equipment for a brief period or until they felt comfortable with the movement. After that, they warmed up by cycling for 5 minutes on a Monark cycle ergometer (model 828E) with a perceived exertion rating ranging between 11 and 12 on the Borg's scale and were given enough time (15+ minutes) to extinguish any potentiation effects.
2.3.1 Pre-conditioning test (pre-test)
Shortly after the warm-up, participants were placed in a supine position on a secured and properly built sledge (wooden surface covered with rubber) that could slide with low friction on a metal frame. Their bodies were securely strapped at a 45° angle. The participant’s foot was positioned at a 90° angle on top of two Bertec force plates (Bertec, USA). After being properly positioned, subjects were instructed to bend the left leg and place the foot in the sliding platform away from the force plate and as stable as possible and then forcefully jump by plantar flexing at the ankle. They performed 2 trials of maximal ankle hops on the right ankle, each trial consisted of 2 jumps. There was 1 minute of passive rest between both trials. Audio feedback was prerecorded and provided to all participants in order to maintain a time frame consistency during sessions as well as between participants. The audio file would cue the participant before the jump with the feedback of “ready, set, go”.

![Figure 5 - Setup of the sledge](image)

2.3.2 Maximal Voluntary Isometric Contraction (MVIC)
Subsequently, participants were placed in an isokinetic dynamometer (Isomed 2000; D&R Ferstl GmbH, Henau, Germany). The subjects were in prone with the right ankle at 90° and the foot at a foot plate, the knee was kept fully extended. After alignment of the ankle joint axis with the rotational center of the dynamometer shaft, the right foot was securely strapped to a custom-made footplate, whereas the rest of the body was properly fixed with straps for upper body, hip, and legs. The range of motion test and gravity correction was then performed according to the isokinetic dynamometer software and manufacturer’s guidelines. After being
properly placed in the dynamometer, participants performed a 6 s MVIC (plantar flexion). Audio feedback instructed subjects by the cues of: “ready, set, go, stop”.

![Isokinetic dynamometer](image)

*Figure 6 – isokinetic dynamometer (this setup is not the same as used in this study)*

**2.3.3 post-conditioning test (post-test)**

Immediately after the 6-second MVIC, subjects walked back to the sledge to perform the post-conditioning tests (post-tests). All subjects performed two consecutive hops on their right ankle at 30-seconds, 90-seconds, 3 minutes, 5 minutes, 8 minutes, and 15 minutes after the 6-seconds MVIC. All the set-up was the same and participants still had the audio aid cued by a “ready, set, go” feedback, making sure the time points of all hops were controlled.
2.3.4 Data analysis
All sledge hops were captured by a four-camera motion capture system (Oqus 4, Qualisys, Sweden). Qualisys Track Manager software (version 2.7, Qualisys, Sweden) was used to record the position of seven passive reflective markers. One marker was placed laterally on the sledge. Six markers were placed at the hallux, 5th metatarsal, malleolus, knee, hip and humerus. For the last three body parts, the markers were placed laterally. Kinematic and Kinect data was exported to Visual3D (version 4, C-Motion, USA) and low-pass filtered with a 50-Hz cutoff frequency. All data was analyzed using the Pipeline in Visual3D. According to the user’s manual the Pipeline processor provides access to the core of Visual3D functionality through commands. Each function is represented by a command. The Pipeline is typically used to automate processing steps. The Pipeline has the ability to manage files, define events, execute signal processing computations, create and edit modes, create and modify reports, and generated statistics. Edit boxes are usually provided for configuring each process step. The first step with each subject and each jump was to setup a baseline. The baseline was defined as a three second period where the subject was standing completely still on the force plate, two events were manually created in the beginning and at the end of the three seconds, they were named as “BASE_1” and “BASE_2”. After establishing the baseline area, the command “metric_mean” was used the calculate the average force in N that was being applied in that area, the result was considered the baseline. All the force data was calculated from the Z axis since the force was applied horizontally. The second step was to define events for take-off and landing. To do so, the command “Event_threshold” was used twice to identify the first moment that force became zero (take-off) and the first moment that force was higher than zero. The process was done in all the jumps from every subject, take-off was labeled as “TAKE_OFF1” and “TAKE_OFF2” and the landing was labeled as “LANDING1” and “LANDING2”, since in every timeframe two jumps were performed. The last step of the initial setup was to determine the concentric positive onset, which has been defined as the point at which force increases above a specified threshold (Maffiuletti et al., 2016), in this case, the baseline value. Identifying this point is an automated method, the threshold level has been set in absolute units like 7.5N higher than baseline values (Blazevich et al. 2009) or relative to individual MVC, like 2.5 % of a MVC (Johnson et al., 2015). In the current paper, the threshold was identified using the command “Event_threshold” and set to be equal to 3% higher of the average baseline value and was named as “ONSET1” for jump one and “ONSET2” for jump two. After completing the setup 6 mechanical variables were calculated. All of them are described in detail below.
Peak force (FPEAK): The command “Event_Global_Maximum” was used between the beginning of the jump and take-off to create an event at the highest force value. The event was labeled as “FPEAK1” and “FPEAK2”. Following the event labeling, the command “Metric_signal_at_event” was selected to define in N the force value at the event.

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Figure 7 - Illustration of the FPEAK represented as the highest value in Newtons during the concentric phase in one example of an ankle hop. The event highlighted in blue displays the exact place where the peak force happens.

Average rate of force development (AVG RFD): To obtain the result, it was necessary to know the time it took from the concentric positive onset to peak force (Time to peak force). To do that, the command “Time_between_events” was used between those two events and the metric result was named “TTP1” and “TTP2”. The AVG RFD was obtained by dividing the value at peak force (FPEAK) by the time to peak force (TTP). The calculations were done in an excel sheet and the results were expressed in [N·s⁻¹].

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Figure 8 - Illustration of the AVG RFD: The FPEAK is represented in the blue highlight and TTP was considered as the time it took from the positive concentric onset, highlighted in red, to FPEAK.

Rate of force development from 0 to 50ms (RFD 0-50ms): To establish the 50ms point it was necessary to manually place a marker on the “concentric positive onset” event, and, from there, also manually, press the “forward” box frame by frame to find the 50ms mark after concentric positive onset, where the events “50MS1” and “50MS2” were created. To calculate the RFD 50ms, the command “Metric_signal_at_event” was used to find the force value (N) at 50MS1 and 2. Each value was then divided by 50 milliseconds to reach the results expressed in [N·s⁻¹].

*due to copyright reasons, the images are missing in the electronic edition*

Figure 9- Illustration of the RFD 0-50ms: The blue highlight represents force at 50ms and the red highlight represents the concentric positive onset.
Rate of force development from 0 to 90ms (RFD 0-90ms): The process to find the results were identical to the RFD 0-50ms, except that the manual frame by frame was done until it reached the 90ms mark, and that mark was used to run the calculations in the excel sheet. In both cases, signal values at the events were checked to make sure that event was being created in the correct timeframe. The results were also expressed in [N·s⁻¹].

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Figure 10 - Illustration of the RFD 0-90ms: The blue highlight represents force at 90ms, and the red highlight represents the concentric positive onset.

Time in air (TIA): Time in air was used in this study as a predictor of jump height performance. To calculate it, the command “Time_between_events” was used for all jumps with “TAKE_OFF” and “LANDING” selected as the events that time was taken from. The results were expressed in MS as the time it took from take-off to landing.

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Figure 11 - Illustration of TIA represented as the time from take-off (blue highlight) to landing (red highlight).

Time to take-off (TTT): This variable represents the time taken from concentric positive onset to takeoff. It is a measure of how fast the concentric portion of the jump was. To calculate it, the command “Time_between_events” was used between “ONSET” and “TAKE_OFF” in each jump. The values were expressed in MS.

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Figure 12 - Illustration of TTT represented as the time from concentric positive onset (highlighted in red) to take-off (highlighted in blue).

2.3.5 Statistical analysis
The data was analyzed using JASP (Version 0.14.1 [Computer software]). All data was described as mean and standard deviation. Two separate and completely identical analyses
were performed for each pre-test. Data distribution was analyzed using the Shapiro-Wilk test. A repeated measures ANOVAs (with the factor time) was performed for the mechanical variables FPEAK, Time to FPEAK, AVG RFD, RFD 0-50ms, RFD 0-90ms, TIA and TTT. Whenever a significant difference was observed, a Post Hoc test with a 95% confidence interval was applied and a Holm correction was used. Differences were considered significant at $p \leq 0.05$. A Cohen’s d test was used to better identify where the differences were found, however the Cohen’s d test does not correct for multiple analyses; therefore, this data was not used to further evaluate the results.

3. Results

3.1 Peak Force (FPEAK)

Among the 10 physically active subjects a significant main effect of time was found for FPEAK in both pre-test 1 ($p = 0.041$) and pre-test 2 (0.013) when comparing to post-test.

After conducting a Post hoc analysis, Holm's correction still showed significant changes for FPEAK pre-test 1 at the time point of 30-seconds ($p = 0.020$) but no changes were found at any of the time points. The descriptive plots below (Fig. 13) clearly displays the summary of the results, showing the significant change in 30-seconds for pre-test 1 (A) and no significant change for pre-test 2 (B), even though for pre-test 2 the highest effect is also seen for 30-seconds, however the error bar demonstrates a high variability of data, implying uncertainty in the reported measurement.
The descriptive data with all possible comparisons are displayed in table 2. Data is described in Newtons (N).

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (N)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1</td>
<td>546.4</td>
<td>97.5</td>
</tr>
<tr>
<td>Pre 2</td>
<td>568.5</td>
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<tr>
<td>30sec</td>
<td>605.1</td>
<td>77.0</td>
</tr>
<tr>
<td>90sec</td>
<td>556.3</td>
<td>113.1</td>
</tr>
<tr>
<td>3min</td>
<td>549.7</td>
<td>123.6</td>
</tr>
<tr>
<td>5min</td>
<td>572.5</td>
<td>122.4</td>
</tr>
<tr>
<td>8min</td>
<td>547.4</td>
<td>133.7</td>
</tr>
<tr>
<td>15min</td>
<td>543.4</td>
<td>124.7</td>
</tr>
</tbody>
</table>

3.2 Average rate of force development (AVG RFD)

There was no interaction effect between the baseline tests and time points (p = 0.95, p = 0.462).

The average rate of force development descriptive data can be seen in table 3. Even though no significance was demonstrated, the table shows that there is a tendency of progressive increase for AVG RFD up to the 3-minutes mark and at 5-minutes it starts to progressively decrease. Data is described in Newtons per second (N s).
### 3.3 Rate of force development from 0-50ms (RFD 0-50ms)

When analyzing RFD 0-50ms, no significant differences were shown between any of the comparisons (p= 0.217, p = 0.283).

Like AVG RFD, the descriptive data of RFD 0-50ms also show a progressive enhancement until the 3-minutes mark even though no significance was demonstrated. Table 4 displays all the descriptive data from RFD 0-50ms. Data is described in Newtons per second (N s).

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (N s)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1</td>
<td>4093.0</td>
<td>1223.6</td>
</tr>
<tr>
<td>Pre 2</td>
<td>4379.1</td>
<td>1562.1</td>
</tr>
<tr>
<td>30sec</td>
<td>4502.3</td>
<td>954.4</td>
</tr>
<tr>
<td>90sec</td>
<td>4566.6</td>
<td>1266.2</td>
</tr>
<tr>
<td>3min</td>
<td>4590.5</td>
<td>1504.6</td>
</tr>
<tr>
<td>5min</td>
<td>4428.1</td>
<td>1421.3</td>
</tr>
<tr>
<td>8min</td>
<td>4244.3</td>
<td>1253.2</td>
</tr>
<tr>
<td>15min</td>
<td>4225.6</td>
<td>1465.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (N s)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1</td>
<td>4553.9</td>
<td>1604.9</td>
</tr>
<tr>
<td>Pre 2</td>
<td>4725.9</td>
<td>1922.1</td>
</tr>
<tr>
<td>30sec</td>
<td>4468.8</td>
<td>1561.9</td>
</tr>
<tr>
<td>90sec</td>
<td>5304.7</td>
<td>1988.2</td>
</tr>
<tr>
<td>3min</td>
<td>5643.1</td>
<td>2207.4</td>
</tr>
<tr>
<td>5min</td>
<td>4910.7</td>
<td>2250.8</td>
</tr>
<tr>
<td>8min</td>
<td>4908.1</td>
<td>1985.5</td>
</tr>
<tr>
<td>15min</td>
<td>4822.0</td>
<td>2297.6</td>
</tr>
</tbody>
</table>
3.4 Rate of force development from 0-90ms (RFD 0-90ms)

The RFD from 0-90ms did not show any significant differences between pre- and post-tests at any time point (p = 0.151, p = 0.332).

The descriptive table of RFD 0-90 (Table 5) show a similar pattern to both AVG RFD and RFD 0-50ms. The data can be seen below. Data is described in Newtons per second (N s).

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (N s)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1</td>
<td>4739.6</td>
<td>1453.9</td>
</tr>
<tr>
<td>Pre 2</td>
<td>4990.0</td>
<td>1686.4</td>
</tr>
<tr>
<td>30sec</td>
<td>4922.2</td>
<td>1118.1</td>
</tr>
<tr>
<td>90sec</td>
<td>5224.6</td>
<td>1419.6</td>
</tr>
<tr>
<td>3min</td>
<td>5228.2</td>
<td>1522.8</td>
</tr>
<tr>
<td>5min</td>
<td>4995.0</td>
<td>1752.8</td>
</tr>
<tr>
<td>8min</td>
<td>4659.9</td>
<td>1543.5</td>
</tr>
<tr>
<td>15min</td>
<td>4766.4</td>
<td>1793.1</td>
</tr>
</tbody>
</table>

3.5 Time in the air (TIA)

Repeated measures ANOVA did not find any significant differences in TIA for pre-test 1 (p = 0.462) and pre-test 2 (p = 0.383) when comparing to all time points of the post-test.

The descriptive data for TIA is displayed in table 6. Data is described in milliseconds (ms).

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (ms)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1</td>
<td>0.53</td>
<td>0.07</td>
</tr>
<tr>
<td>Pre 2</td>
<td>0.53</td>
<td>0.07</td>
</tr>
<tr>
<td>30sec</td>
<td>0.53</td>
<td>0.04</td>
</tr>
<tr>
<td>90sec</td>
<td>0.53</td>
<td>0.07</td>
</tr>
</tbody>
</table>
3.6 Time to take-off (TTT)

For TTT a significant change was observed at some time point for both pre-test 1 (p = 0.002) and pre-test 2 (p = 0.014). After conducting a post hoc analysis to investigate further, Holm correction did not show any significant differences for any time points for none of the pre-tests.

The highest effects towards a faster TTT were shown in both pre-tests at 90-seconds and 3 min after a 6-second MVIC. The slowest TTT was at 5min and 30-seconds after CC for both pre-test 1 and 2. These results are shown in the descriptive table below (Table 7). Data is described in milliseconds (ms).

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (ms)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1</td>
<td>246.6</td>
<td>22.0</td>
</tr>
<tr>
<td>Pre 2</td>
<td>249.9</td>
<td>28.5</td>
</tr>
<tr>
<td>30sec</td>
<td>259.4</td>
<td>36.6</td>
</tr>
<tr>
<td>90sec</td>
<td>231.4</td>
<td>20.9</td>
</tr>
<tr>
<td>3min</td>
<td>234.9</td>
<td>20.6</td>
</tr>
<tr>
<td>5min</td>
<td>261.1</td>
<td>32.1</td>
</tr>
<tr>
<td>8min</td>
<td>244.0</td>
<td>22.9</td>
</tr>
<tr>
<td>15min</td>
<td>252.4</td>
<td>30.7</td>
</tr>
</tbody>
</table>
4. Discussion

The aim of this study was to investigate effects of a 6-seconds MVIC of the plantar flexors on subsequent ankle hops performed only by plantar flexing at the ankle. The times points selected for the post-conditioning ankle hops were 30-seconds, 90-seconds, 3-minutes, 5-minutes, 8-minutes, and 15-minutes. The rationale behind this is that previous studies has already observed the timing and duration of the assessments and recommend that maximal twitch PAP happens immediately after conditioning (Gago, Marques, Marinho & Ekblom, 2014; Baudry & Duchateau, 2007), and maximal PAPE happens between 7–10 minutes in explosive voluntary tasks (Wilson et al., 2013). This study also aimed to trace a parallel between its results and the results found by Gago et al., (2020), that observed PAP in twitch contractions of the plantar flexors after a 6-seconds MVIC and also observed an increase in peak torque and rate of torque development during maximal voluntary plantar flexion performed at a moderate controlled velocity following the same protocol to induce potentiation. This study brings a third level to the previous findings of Gago et al., (2020), adding a higher velocity more field base movement performed in very similar conditions to both samples mentioned previously.

The main findings in this study are that a 6-sec MVIC can improve FPEAK in the active population but not jump performance in height. There seems to be a minimal effect of PAP in functional performance, however the effect is not large enough to induce performance enhancement in a laboratory setting or in the field. It is worth to note that for people that are fiber type II dominant, the enhancement might be significant in terms of performance enhancement. More studies need to be conducted with this specific population.

4.1 Peak Force (FPEAK)

The human ankle plantar flexors, consisting primarily of the soleus, medial gastrocnemius, and lateral gastrocnemius muscles, play an indispensable role in running and walking, providing contribution to all the major lower-limb muscles to the upward and forward accelerations of the body’s center of mass (Lai et al., 2016). In terms of sports performance, during a triple jump for example, the peak ankle moment exhibits high values within a relatively small range. The moment at the ankle joint during this action can even be the largest moment among all joints (Graham-Smith, 1999). In the present study, FPEAK during plantar flexion ankle hops
was significantly enhanced 30-seconds after a 6-seconds MVIC when comparing post-tests to pre-test 1. Interestingly, no significance was shown when the comparisons were made with pre-test 2, suggesting that a progressive potentiation occurred from pre-test 1 to pre-test-2 and subsequently to the 30-seconds time point. At the 90-second mark, FPEAK was already lowering down, indicating fatigue setting in and overcoming potentiation effects. The enhancement observed in the 30-seconds time point represented a 12% increase when compared to pre-test 1 and 7.9% when compared to pre-test 2.

In comparison with the parallel study by Gago et al., (2020) FPEAK enhancements did not follow the same time pattern. In this published article, there was an increase in peak torque in the concentric contraction of a moderate speed (60°·s⁻¹) maximal plantar flexion at 90-seconds, 3-minutes and 5-minutes. That represented 5.7%, 6.0%, and 5.9% increases from the baseline at the respective time points. These results indicate that a different pattern in the enhancements can be observed in moderate speeds when compared to more explosive tasks. In that sense, our results were closer to the ones found by both Fukutani et al., (2013) and Miyamoto et al., (2011) that analyzed PAP effects during plantar flexion in a faster voluntary concentric contraction (180°·s⁻¹) and observed a potentiation effect earlier in relation to CC (5-seconds and 1-3 min respectively). The differences in potentiation time points might be due to differences in the experimental protocols since PAP might be induced differently depending on how the familiarization process and warm-up protocol were organized. Regardless, the early potentiation during more explosive tasks might be due to myosin regulatory light chain (RLC) phosphorylation, since the time frame of this effect matches the enhancements observed in the present study (Sweeney et al. 1993). To extend on the topic, the effects of potentiation are more prominent when interaction between actin and myosin is insufficient. During high velocity actions, the number of attached cross-bridges tends to be smaller, suggesting that potentiation will be more pronounced when the joint angular velocity is higher, like the maximal ankle hops presented in this study (Sweeney et al. 1993, Piazzesi et al., 2007).

It's important to state that, even though a significant change was observed for FPEAK, there are reports in the literature indicating that there is no significant correlation between FPEAK and jumping performance (Wisløff et al., 2004; Young, Wilson & Byrne, 1999). In fact, FPEAK has been correlated with performance against heavy loads such as heavy squats, but not in more explosive tasks such as jumping or hopping (Kawamori et al., 2006). A better way to relate peaks of force to performance would be by using FPEAK relative to body weight such
as Markström & Olsson (2013) did and found that relative FPEAK can be a predictor for maximal running velocity through 10- and 60-m time. Another study by McBride et al., (2010) also portrays FPEAK as a poor predictor of jump performance, and as it seems, Peak Power (PP) would be a more suitable measure.

4.2 Average rate of force development (AVG RFD)

Rate of force development (RFD) can be defined as the slope of the time-force/torque curve (Aagaard et al. 2002). The same author argues that RFD is important because it measures the speed at which the contractile elements of the muscle can develop force, or put simply, it is a measure of how explosive a person can be. Developing more explosive movement may improve daily life and also sports performance. In fact, higher RFDs have been directly linked with better jumping ability (Laffaye, Wagner, and Tombleson, 2014; Laffaye & Wagner, 2013; Haff et al., 2005; McLellan, Lovell & Gass, 2011). Average rate of force development (AVG RFD) is obtained through the division of the peak force value by the time to achieve peak force (Haff et al., 2015).

In the present study no significant differences were found for AVG RFD, however, it is important to note that a progressive increase was observed from pre-test 1 up to the 3 minutes mark, reaching a 11.67% increase according to our normalized data. Even though such an increase was observed, probably due to the low number of subjects, the margin of error was too high and therefore no significance was demonstrated. For Gago et al., (2020), twitch RFD was increased from 5 seconds up to 8 minutes after MVIC-cc. The twitch RFD behaved differently when compared to the concentric contraction RFD. The second showed potentiation effects from 90-seconds up to 5-min. According to Miyamoto et al., (2011), improved maximal voluntary dynamic performance will be demonstrated when there is absence of fatigue, implying that a proper recovery time must be given after MVC-cc. The delay of onset of the potentiation in voluntary contractions is probably explained by the coexistence of the dual effects of the conditioning MVC (i.e., PAP and fatigue) (Fowles & Green, 2003; Garner, Hicks & McComas, 1989). This relationship has been observed in the literature after a 6-second MVC-cc, suggesting a subsequent impairment of dynamic performance immediately after the MVC (Gago et al., 2020, Fukutani et al., 2013; Miyamoto et al., 2011). In the present study even though no significant differences were demonstrated, there was a tendency of increase matching the same timeframe observed by Gago et al., (2020), where RFD stayed above baseline until the 5-minute mark. And, differing from the authors findings, in the present study
that tendency of increase appeared already at the 30-second time point, however this early effect might have occurred as a consequence of a theoretical potentiation already from pre-test 1. A maximal plantar flexion ankle hop, thereby, might be sensitive enough to induce PAP, which would already be shown in pre-test 2 (1 minute later) in the present study. It's important to state, that even though no statistical significance was demonstrated in our study, we cannot infer that there was no effect of PAP since we had a small number of subjects and also PAP can affect different populations in different manners, i.e: A more pronounced PAP observed in the literature in type II fiber predominant individuals (Moore and Stul, 1984). Another important aspect to consider is that in the study by Gago et al., RFD was improved during the 0-200, 100-200 and 50-200 phases of the concentric plantar flexion but not from 50-100ms. The results found by the authors indicate that PAP effects are more relevant in tasks where force production exceeds 100ms. In the current study, it was not possible to evaluate the same time frames because of the nature of the task. Ankle hops present faster contractile characteristics and subjects would achieve peak force values before the 200ms mark. Because of that, it was decided to use AVG RFD instead of a 0-200ms mark. In the future it could be interesting to analyze tasks with identical contraction times.

Finally, both studies demonstrated a progressive decrease in RFD after the 5-minute point. The decrease probably did not indicate a reduced PAP since twitch RFD stayed potentiated until the 8-minute mark, is more probable to assume an effect of fatigue surpassing PAP effects on the voluntary contractions.

### 4.3 Rate of force development from 0-50ms and 0-90ms

In maximal force exercises (i.e squats, deadlifts) there is strong evidence that late phase RFD (>250ms relative to the contraction onset) can contribute to performance (Mirkov et al., 2004, Andersen and Aagaard, 2006). The present study analyzes ankle hops, which are a much faster type of action. In our case, it might be that early stage RFD (<100ms) plays a bigger role than late stage, since peak force was always achieved somewhere between 100 and 200ms in every subject. Indeed, it has been demonstrated that RFD is influenced by different physiological parameters at early (<100ms) and late phase (>250ms) relative to contraction onset. There are indications that neural factors play a major role in early-stage RFD (<75 ms) of a rapid contraction (Aagaard et al. 2002a; Klass et al. 2008). And when dealing with longer duration, the voluntary RFD becomes more strongly influenced by the speed-related properties of the
muscle and the contraction maximal force characteristics (Andersen and Aagaard 2006; Folland et al. 2014). The fact that early-stage RFD is influenced by neural factors such as motor unit (MU) recruitment and discharge rate implies a great interindividual variability in MU behavior during rapid contractions (Folland et al. 2014; Klass et al. 2008). And the fact that this variability can be greater in the earliest stages of the contraction (first 40–50 ms) can partially explain the role of neural factors contributing substantially to the between-subject variance in terms of RFD during those stages (Folland et al. 2014). This variance between subjects can be reduced relatively quickly through learning processes. In the literature, it was observed that simple movements performed with muscles that only span a single joint can improve activation patterns substantially after a single practice session (Jensen et al. 2005; Lee et al. 2010).

Another important aspect that can influence early stage RFD is fiber type. When we look at the plantar flexors the most prominent fiber type is the slow twitch type I. The soleus muscle contains 75% and gastrocnemius 45–75% type I fibers (Dahmane et al. 2005; Luden et al. 2008). However, the quantity of type II fibers can vary across subjects, and these variances might strongly influence RFD values in early stages (Andersen 2001).

For the present study, it was decided to use the 0-50ms and 0-90ms time intervals of RFD. The reasoning behind this choice came from the fact that subjects achieved their peak force before the 200ms mark, and since AVG RFD was also taken, it made sense to analyze the earliest stages. Another point is that the ankle joint and plantar flexion play a major role during sprinting a reactive jumping (Graham-Smith, 1999), and these actions are considered as fast stretch shortening cycle (SSC), and in this case, early-stage RFD seems to be of the most importance. For example, a countermovement jump (CMJ) is classified as a slow-SSC movement as the duration of the SSC lasts approximately 500 milliseconds, therefore it could be that late-stage RFD is more important in this case (Laffaye, Wagner, & Tombleson, 2014). On the other hand, sprinting is classified as a fast-SSC movement as the duration of the SSC lasts between 80-90 milliseconds (Taylor & Beneke, 2012), implying that the early stages are not only more important but the only stages present during this type of action.

Regarding the results, the current study did not find any significant changes for any of the time-intervals. These results go along with the ones found by Gago et al., 2020. However, set aside non statistical significance, a 19% and 25% enhancement were observed for 0-50ms timeframe
at 90-seconds and 3-minutes post-CC respectively. And also, a 12% and 11% for 0-90ms timeframes at the same time points. The lack of significance in this case might reflect the above-mentioned variabilities in terms of early-stage RFD according to each individual. It is important to state that in similar studies no tensile properties of the muscle-tendon unit (MTU) was influenced by both isometric contractions or repetitive hopping. (Gago et al., 2020, Gago et al., 2014, Peltonen, 2010), and since it is unlikely that any PAP effects have been expressed in such early stages, theoretically the subjects who achieved a higher performance might have done so via neural facilitation mechanisms, from the MVIC or even from the ankle hops themselves, or simply by having a faster learning curve for this specific task. In order to better understand the mechanisms behind the results or even to observe more significance, it is important to analyze a higher number of subjects where we also account for EMG data and that these subjects are subdivided in relation to their fiber type composition.

4.5 Time in the air (TIA)

TIA in this study is a representative of jump height. Studies involving jump height and post-activation potentiation have been documented before. Arabatzi et al., (2014) showed that a 3×3-s maximal isometric squat increases squat jump height in adult men, but not in children or women. In a meta-analysis by Gouvêa et al., (2013), the authors concluded that a rest interval of 0–3 min induced a detrimental effect on jump performance, but the range of 8–12 min had a beneficial impact on jump height. In the current study it was not observed either a significant detriment or improvement of jump performance. However, it is interesting to notice that whilst other variables showed slightly non-significant improvements, in the case of TIA a slight decrease in jump height was observed, demonstrating that functional performance tends to be a complex matter to analyze. It is important to note that different studies show different protocols, leaving unclear if the effects were due to PAP or PAPE. Meta-analyses specially can be fairly inconclusive since they portray studies that differ in terms of protocol and individual characteristics of the subjects. In the current study, even though FPEAK was higher at 30-sec when compared to pre-test 1 and even though the parallel study by Gago et al., (2020) demonstrated PAP effects, that did not imply in performance enhancement in this particular functional task. The type of conditioning activity and the characteristics of the subjects seem to play a major role when it comes to performance enhancement. Two examples of this are the study by Seitz & Haff (2016) where the authors observed that plyometric exercises work better.
as a conditioning activity than regular squats for jump performance. And also, the study by Gołaś et al., (2016) where the results confirmed the effectiveness of PAP with well-trained athletes during explosive motor activities, in the case of the present study subjects were active but not athletes.

4.6 Time to take-off (TTT)

The TTT refers to the time it takes from the beginning of the concentric positive onset to the end of takeoff. No studies were found looking into the importance of TTT. However, in theory, TTT might play a role in exercises or sport actions that demand a faster rather than a stronger type of action. The current study did not show any significant differences in either pre-test 1 or 2. However, the pattern of slight improvement was the same as the improvement observed for AVG RFD, which is expected since both measures are related to how fast force is being developed. Those improvements match the post-activation potentiation effects seen by Gago et al., (2020) as mentioned previously.

4.7 Practical implications

As shown in the results, the PAP effect obtained in the parallel study was not enough to produce functional improvement in ankle hops performed on a sledge in physically active subjects. Adding to it, the authors cannot affirm that a sledge hop can be considered applicable to any sport or non-isolated exercise due to the complex characteristics that surround movement. Since muscles and joints work together in a synchronized fashion and environmental constraints plays a role in movement performance, in theory, the effects from PAP observed in a sledge setting would even lessen in a field environment.

In terms of pre-activity routines, warm-ups can reduce injury and improve performance. When well-designed warm-up routines are prescribed by exercise professionals, they will maximize the athletic potential in sports or for regular gym goers. A well-designed warm-up can increase blood flow, muscle temperature, core temperature, and disrupt temporary connective tissue bonds. These effects can offer positive outputs on performance such as faster muscle contraction and relaxation, greater RFD, faster reaction time, improvements in muscle strength and power and improved oxygen delivery (Jeffreys, 2007).
Based on the warm-up approach mentioned above, it is highly unlikely that anyone would only use a 6-sec MVIC before any activity. A properly structured routine including a large variability of movement is the more indicated approach in that scenario. Therefore, future studies focused on finding field-based solutions should aim on finding the most appropriate protocol including several exercises for each specific activity. In such conditions, it might even be that isometric contractions on different exercises combined with several other types of warm-up exercises could be beneficial for performance. Comparing a full warm-up routine containing isometric exercises to a routine with no isometric exercises could be a path to take this research further into the field.

4.8 Limitations

A limitation of this study was that a short voluntary familiarization session was done with the ankle hops. It is possible that the number of repetitions was not enough to properly accustom the participants with the unique technique of jumping on a sledge with the leg strapped. This could in turn have had an impact on the results since the learning curve might influence the results and mask PAP effects.

This study calculated the average time of two jumps. The results may have been different if the best attempt would have been chosen instead of the average.

One of the main limitations of this study was the low number of subjects and the diverse nature of them. In this type of protocol age, sex, fiber type, training experience and other factors might heavily influence the results. In this study subjects were composed of 8 men and 2 women, all with different training experiences; among that, only one subject was type II fiber dominant. The group number and individual characteristics did not allow for a proper statistical significance, leaving the discussion more in the field of assumptions.

In this study EMG signals from plantar flexors were not investigated. It could have been that the signaling or activation patterns would modify with the CC. This could give a better insight on PAP mechanisms and performance enhancement.

A major limitation is the time points chosen during the analyses. It is possible that the jumps at different time points were affected by fatigue, and, since they were eight different time points
where two jumps were performed, statistical power was reduced. In the future, researchers should run experiments where the task is performed on less time points. Perhaps using literature to establish the most common time points where you can see PAP or PAPE effects and using only two (i.e.: 3 and 12 minutes) can bring more statistical relevance to the research. In the present study, perhaps higher statistical power could be achieved by only looking at the time points where the significant results were seen in the parallel study by Gago et al., (2020).

Future research should investigate the different kinetics of ankle hops after a CC with a higher number of subjects. Researchers should also consider neural factors via EMG to be able to understand the mechanism of PAP in functional tasks from a different perspective. Also, it’s important to make a clear distinction between fiber type groups and level of physical capacity. It could also be interesting to use the same isolated conditions as this study was able to produce (sledge), for different joints and muscle groups. From a performance perspective, these changes could assist researchers in the understanding of PAP effects and eventually increase training and competition performance. On the field, researcher must attempt to include MVIC in a broader warm-up routine and compare it to the same routine with no isometric exercises in order to evaluate the potential of MVIC in sports performance.

5. Conclusion

The main findings of this study were that PAP induced by a 6-sec MVIC of the plantar flexors, differing from other studies, could not enhance functional performance of a sledge ankle hop. Experiments with PAP in joint isolated conditions facilitate the understanding of the mechanisms behind this type of warm up and allow for future research to explore the field deeper. While this protocol has previously been shown to temporarily enhance the contractile properties of the plantar flexors as assessed by a single twitch, such effects may not be readily transferred to functional tasks.

6. References


dynamic mid-thigh clean pulls performed at various intensities. Journal of strength and conditioning research, 20(3), 483–491. https://doi.org/10.1519/18025.1


