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A comparison of muscle activity between strict, kipping and butterfly pull-ups

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ABSTRACT

The kipping pull-up (KPU) and butterfly pull-up (BPU) are variations of the strict pull-up (SPU) where an athlete uses hollow and arched body positions to gain momentum, before accelerating vertically. Understanding the muscle activity of each of these exercises will help coaches better utilise them within a strength and conditioning programme. The aim of this study was to compare upper and lower body muscle activation between the SPU, KPU and BPU during the concentric and eccentric phases of each exercise. 11 participants had surface electromyography data collected from three upper and three lower body muscles while completing each pull-up variation. Peak EMG data from each phase for each muscle from the SPU were used to normalise peak KPU and BPU EMG data. A repeated measures ANOVA with Bonferroni post hoc testing was used to identify significant differences between each variation. The results show significantly reduced muscle activation in the bicep brachii during the concentric ($p < 0.05$; $d = 1.1$) and eccentric ($p < 0.05$; $d = 1.1$) phases of the BPU, when compared to the SPU. Activation of the latissimus dorsi was significantly lower during the concentric phase of the KPU ($p < 0.02$; $d = 1.2$) and eccentric phase ($p < 0.01$; $d = 1.4$) of the BPU in comparison to the SPU. Furthermore, significantly greater muscle activation was shown in the rectus femoris, gluteus maximus and rectus abdominus in both the KPU and BPU, when compared to the SPU. However, results differed within the concentric and eccentric phases. These findings show that both styles of kipping increase lower body muscle activation and decrease upper body activation in comparison to the SPU. Further, due to the different style of kip, the KPU and BPU display different muscle activations during both the concentric and eccentric phases.

1. Introduction

The strict pull-up (SPU) is a popular exercise in many strength and conditioning programmes (Pate, Burgess, Woods, Ross, & Baumgartner, 1993; Woods, Pate, & Burgess, 1992). The pull-up requires the upper limbs to pull the body (which is in a hanging position while gripping onto a fixed bar) vertically until the chin passes the bar (Ronai & Scibek, 2014; Youdas et al., 2010). The biceps brachii (BB) and latissimus dorsi (LD) are the prime movers of the SPU exercise as the glenohumeral joint and elbow joint go through extension and flexion during the concentric phase, respectively, and are considerably more active during the pulling (concentric) and lowering (eccentric) phase of the SPU than other upper body musculature (Dorma, Deakin, & Ness, 2013). Interestingly, Dickie, Faulkner, Barnes and Lark (2017) highlighted that differences in upper body muscle activation are

seen when comparing the concentric and eccentric phases of the SPU. Further, changes in approach to performing the SPU exercise has seen changes in muscle activation. In 2010, Youdas et al. examined the effect of hand orientations on muscle activity in seven upper body muscles and found the BB produced higher levels of muscle activity when a supinated grip was used compared to a pronated grip. These studies suggest muscle force contributions to the SPU exercise can differ depending on the phase of the exercise and the approach used.

The kipping pull-up (KPU) is a variation of the SPU, where the lower limbs are incorporated to create a greater impulse via an increase in force over a longer duration. This increase in impulse causes greater momentum and velocity during the concentric phase of the exercise. KPU's have recently gained popularity in physical training communities as they allow more reps to be completed in a shorter amount of time, and can be performed by

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athletes who may not have the upper body strength to perform SPU's. KPUs have been compared to a glide kip in gymnastics (Yamasaki, Gotoh, & Xin, 2010), this is largely due to increased contribution of the lower body, when compared to the SPU (Dinunzio, Porter, Van Scoy, Cordice, & McCulloch, 2018). As a result, upper body muscle contributions have been reported to be reduced in the KPU (Snarr, Hallmark, Casey, Nickerson, & Esco, 2015). Snarr and colleagues (2018) reported a decrease in both BB and LD muscle activation during the KPU when compared to the SPU, suggesting an increased emphasis of hip extension to be a possible cause. Dinunzio et al. (2018) provide support for these claims as they reported increased lower limb joint angles and increased lower limb muscle activation.

Similar to the KPU, another variation of the SPU which has also gained recent popularity is the butterfly pull-up (BPU). The BPU requires an advanced form of kipping, where the athlete performs a more cyclical style of kipping in comparison to the up and back motion used for the KPU. The BPU style of kipping can be performed more quickly, though requires greater whole-body coordination to perform. Because of the involvement of the lower body, it is logical to assume upper body muscle activations during the BPU would also be lower in comparison to the SPU. Further, due to the different kipping strategy, there may be different muscle activation patterns between the KPU and BPU. However, no research has currently investigated the BPU.

The programming of these pull-up variations has often been based on the different adaptations they may develop. Typically, the SPU has been programmed for developing upper body weight-relative muscular strength (Pate et al., 1993) and testing upper body muscular endurance (Ronai & Scibek, 2014), whereas the KPU and BPU are often programmed to improve whole body coordination and for increasing the number of repetitions the athlete can perform. However, little is known regarding the muscular strategies needed to perform the KPU and BPU. This knowledge will provide greater understanding of how these exercises effect key physiological adaptations, such as maximal strength, muscular endurance and hypertrophy, enabling coaches and rehabilitators to make better programming decisions. It is therefore the aim of this study to compare upper and lower body muscle activation between the SPU, KPU and BPU during both the concentric and eccentric phases of the exercise. It is hypothesised that upper body muscle activation will be higher in the SPU, lower body muscle activation will be higher in the KPU and BPU, and the KPU and BPU will display different lower body muscle activations throughout the exercise.

2. Methods

2.1. Participants

Ten males (height = 176.6 ± 9.1 cm, weight = 84.9 ± 6.5 kg, age = 33 ± 6 years) and one female (height = 155 cm, weight = 54.9 kg, age = 31 years) volunteered for the study after being recommended by the head coach of a CrossFit affiliate. The inclusion criteria required participants to be injury free, capable of performing five repetitions of each pull-up variation (competency determined by the head coach) and have a minimum of twelve months experience training at the Crossfit affiliate. Prior to the study, participants provided written, informed consent. The

study was approved by the St Mary's University Ethics Committee.

2.2. Procedures

Participants took part in one testing session which was preceded by 48 hours total rest. Before the trial commenced, height (SECA Free Standing Height Measure) and weight (Marsden Weighing Group Portable Scale) were measured. A 10-minute familiarisation of the equipment and procedures was completed before two rounds of a standardised warm up were performed: 250 m row, ten PVC pipe pass throughs, eight kettlebell swings and six banded reverse rows. Following the warm-up, participants completed five repetitions of all three pull-up variations in random order. Each set was followed by 5 minutes rest. Due to its ability to show high muscle activation in a pull-up, a pronated, medium width grip (1.5 times bi-acromial distance) was used for all three variations (Andersen, Fimland, Wiik, Skoglund, & Saeterbakken, 2014). The use of chalk or gymnastic handguards was not permitted. The SPU started in a hanging position with the arms fully extended and feet off the floor. Participants then pulled themselves upward, using only their upper body and without the use of the lower limbs to generate momentum. The top of the repetition was completed when the chin successfully passed over the horizontal line of the bar, before returning to the start point. For the KPU, participants started in the same hanging position (Figure 1a). From the start position they would pull forward with an arched body (extension of the spine and hips – Figure 1b), then back to a hollow position (flexion of the hips – Figure 1c) to generate momentum, before swinging themselves upward with the chin passing over the horizontal line of the bar (Figure 1d). During the descent, they would push backwards and fall down into the hollow position (Figure 1e), before passing through the start point as they completed the next repetition.

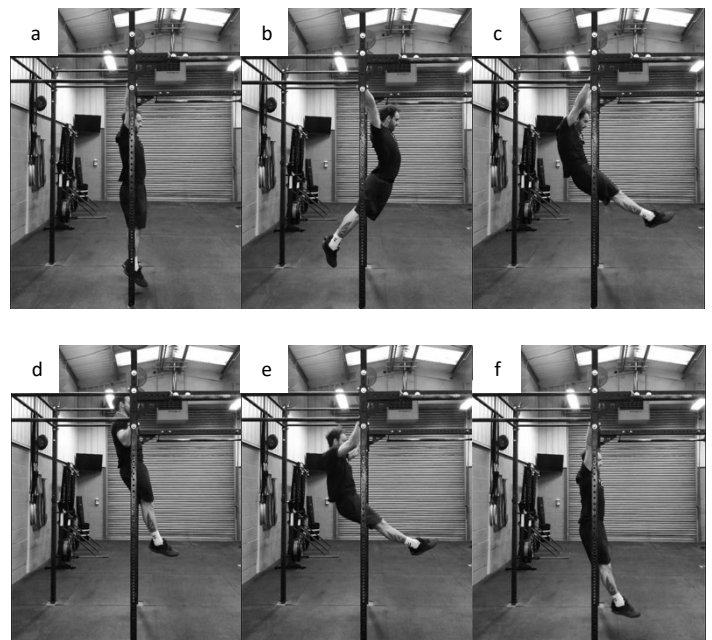


Figure 1: The phases of the kipping pull-up

The BPU also started in the hanging position (Figure 2a). The participant would move into the hollow body shape (Figure 2b) to generate momentum and dynamically pull up to the line of the bar (Figure 2c). On their descent they would pull into the arch position (Figure 2d), before once again passing through the start point (Figure 2e & 2f).

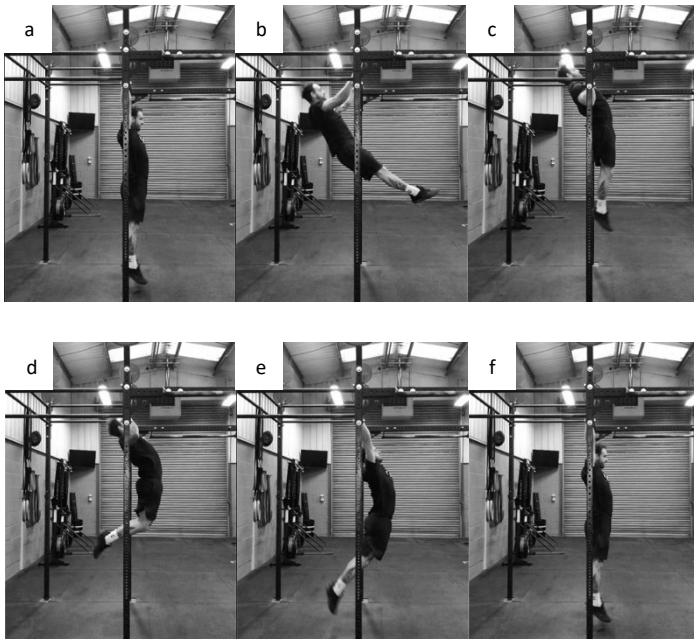


Figure 2: The phases of the butterfly pull-up

A video camera (Panasonic HC-V210 HD camcorder, Panasonic UK Ltd., Berkshire, UK) recording at 50 Hz was placed four metres behind the participant in the frontal plane. The height of the camera was set so that a reflective marker placed on the 7th vertebrae of the cervical portion of the spine was as central as possible when in the hanging start position. The marker was used to identify the concentric and eccentric phases of each exercise. The concentric phase was deemed to have started as soon as the arms were fully extended when descending from the previous repetition with the marker being at its lowest position. The start of the eccentric phase was identified as the moment the athlete began their descent from the peak height achieved when the marker was at its highest position. These kinematic data were analysed using Kinovea analysis software (Kinovea 0.8.15, Kinovea open source, www.kinovea.com).

2.3. Electromyographical Measurement

Electromyographical (EMG) data was recorded using a Delsys Myomonitor® IV Wireless Transmission & Datalogging System (Delsys Inc. Boston, MA, USA) at 1000 Hz. Prior to the application of electrodes, participant's skin was shaved and swabbed. Electrodes were placed on the muscle belly in three upper and three lower body locations, on the participant's dominant side, in line with the muscle fibres. Electrode location followed previous recommendations, which can be seen in Table 1 (Criswell, 2010; Hermens et al., 1999). However, deviation was permitted at the discretion of the lead researcher, when visual identification of the muscle belly differed from recommendations. For example, the muscle belly of the rectus abdominus would often vary between participants in both distance from the xiphoid process and alignment between the linear alba and ribs.

Table 1: Shows electrode location for each muscle and the literature used to identify correct application

Muscle	Electrode location	Reference
Bicep brachii (BB)	Centre of flexed bicep. 60% of the distance from the fossa cubit and medial acromion.	Hermens et al. (1999)
Latissimus dorsi (LD)	4 cm inferior to the angle of the scapula. 50% of the distance from the vertebrae and the lateral border of the latissimus dorsi.	Criswell (2010)
Infraspinatus (IF)	4 cm inferior to the spine of the scapula, in the middle of the fossa.	Criswell (2010)
Rectus femoris (RF)	50% of the distance from the anterior superior iliac crest to the superior part of the patella.	Hermens et al. (1999)
Gluteus maximus (GM)	50% of the distance from the sacrum to the greater trochanter. In correspondence with the greatest prominence of the buttock.	Hermens et al. (1999)
Rectus abdominus (RA)	50% of the distance from the xiphoid process to the naval. 50% of the distance from the linear alba to the ribs.	Hermens et al. (1999)

2.4. Statistical Approach

EMG readings from repetitions 2-4 were collected in order to eliminate any changes in activation and movement pattern during the swing start of the KPU and BPU (Dinunzio et al., 2018). EMG data for each muscle was individually rectified and smoothed using a 101-point rolling average. The timeframe at which EMG recording began was then identified within the video footage in order to synchronise data sets and define the concentric and eccentric phases of each rep. From here, the peak EMG activations for each phase of all three repetitions were identified and averaged (EMGPEAK). This provided an EMGPEAK for each muscle, across each phase, for all three pull-up variations. Data from the SPU was used to normalise KPU and BPU data (Sousa & Tavares, 2012). EMGPEAK values were presented as a percentage of peak SPU muscle activation, with peak SPU muscle activation displayed at 100%. EMGPEAK values were screened for normality using the Shapiro-Wilk test. Data with normal distribution were analysed using a repeated measures ANOVA using SPSS statistics software (SPSS Inc. Chicago, IL). Non-normal distributed data were analysed using a Friedman's ANOVA. A Bonferroni and Wilcoxon signed-rank post hoc tests were used to identify where significant differences occurred in normal and non-normal distributed data, respectively.

3. Results

The Shapiro-Wilk's test identified that the following variables were non-normally distributed. RF and GM for the concentric phase, and BB, RF, GM, RA for the eccentric phase. The appropriate non-parametric statistical tests were therefore used on

these data. Differences in peak muscle activations were shown for both the concentric and eccentric phases of each pull-up variation (Figures 3 to 8). Significant differences in EMGPEAK for the RF (Figure 3) were seen during both the concentric ($X^2 = 16.55, p < 0.01$) and eccentric phase ($X^2 = 20.00, p < 0.01$). EMGPEAK for the RF was significantly higher in the KPU concentric phase ($Z = -2.93, p < 0.01; d = 1.2$) and eccentric phase ($Z = -2.93, p < 0.01; d = 1.3$) in comparison to SPU. RF EMGPEAK was also significantly higher in the BPU in both the concentric phase ($Z = -2.93, p < 0.01; d = 1.4$) and eccentric phase ($Z = -2.93, p < 0.01; d = 1.3$) in comparison to SPU. EMGPEAK for the RF for the BPU was significantly higher than the KPU only during the eccentric phase ($Z = -2.93, p < 0.01; d = 1.1$).

For the BB, significant differences in EMGPEAK during the concentric phase were reported ($F(1.29, 12.95) = 4.23, p < 0.05$). Post hoc tests revealed BB EMGPEAK was only lower during the BPU ($p < 0.05; d = 1.1$) in comparison to SPU. Significant differences in BB EMGPEAK during the eccentric phase ($X^2 = 16.55, p < 0.01$) were also reported. EMGPEAK of the KPU was significantly lower than the SPU ($Z = -2.66, p < 0.01; d = 1.3$) and the BPU ($Z = -2.93, p < 0.01; d = 1.3$). These EMGPEAK differences can be seen in Figure 4.

Significant differences were highlighted for RA EMGPEAK (Figure 5) between pull-up variations during both the concentric phase ($F(1.94, 19.39) = 6.36, p < 0.05$) and eccentric phase ($X^2 = 14.36, p < 0.01$). Post hoc testing for the concentric data found the KPU to have significantly greater EMGPEAK ($p = 0.01; d = 1.3$) in comparison to SPU. Post hoc testing for the eccentric phase showed a lower EMGPEAK for the SPU ($Z = -2.93, p < 0.01; d = 1.6$) and KPU ($Z = -2.85, p < 0.01; d = 1.2$) when compared to that of the BPU.

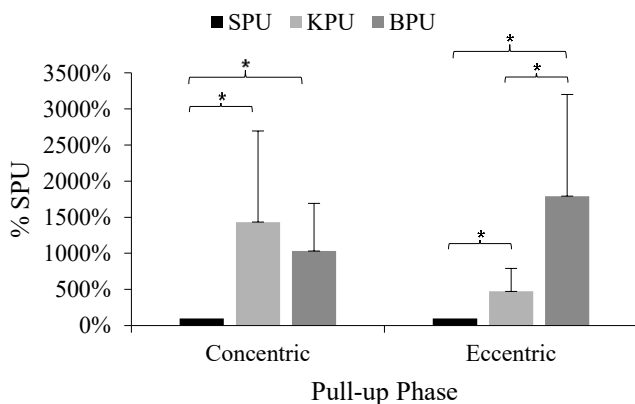


Figure 3: EMGPEAK as % SPU for the rectus femoris across all three variations. Values are given as mean \pm SD. * indicates significant difference ($p < 0.05$).

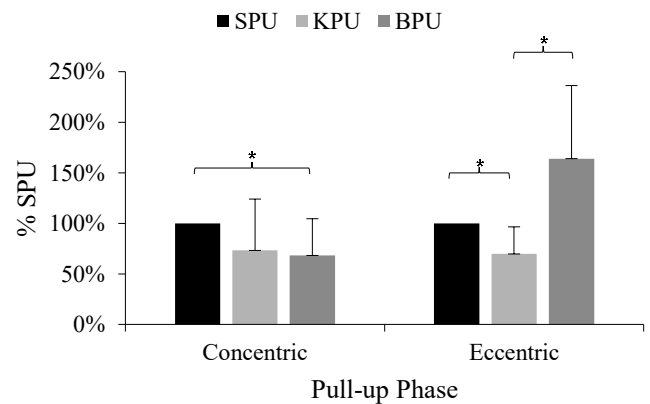


Figure 4: EMGPEAK as % SPU for the bicep brachii across all three variations. Values are given as mean \pm SD. * indicates significant difference ($p < 0.05$).

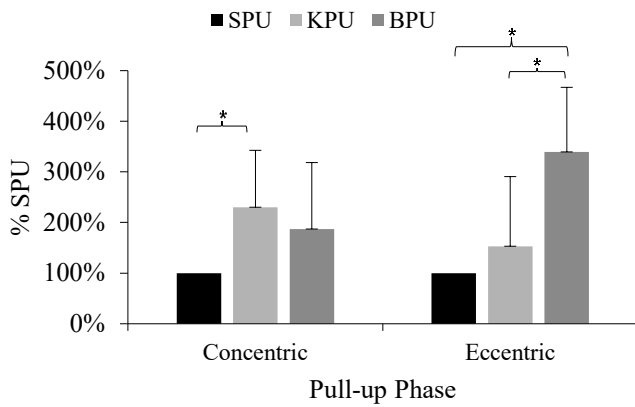


Figure 5: EMGPEAK as % SPU for the rectus abdominus across all three variations. Values are given as mean \pm SD. * indicates significant difference ($p < 0.05$).

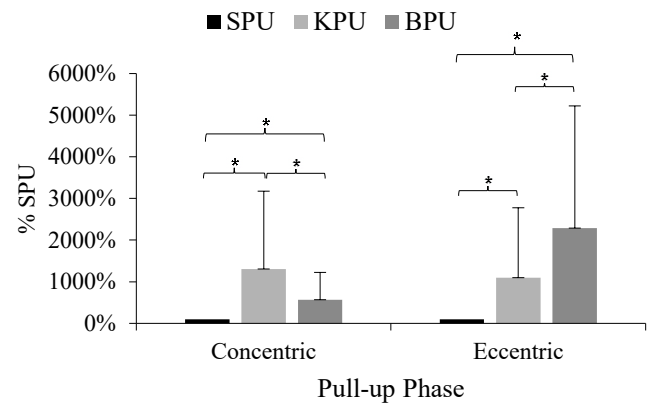


Figure 6: EMGPEAK as % SPU for the gluteus maximus across all three variations. Values are given as mean \pm SD. * indicates significant difference ($p < 0.05$).

Significant differences in EMGPEAK for the GM were also reported between pull-up variations during both concentric ($\chi^2 = 13.27, p < 0.01$) and eccentric phases ($\chi^2 = 20.18, p < 0.01$) (Figure 6). GM EMGPEAK was significantly greater during the concentric phase for both the KPU ($Z = -2.85, p < 0.01; d = 0.8$) and BPU ($Z = -2.40, p < 0.05; d = 0.9$) in comparison to the SPU. Similarly, GM EMGPEAK was significantly greater for the KPU ($Z = -2.76, p < 0.01; d = 0.8$) and BPU ($Z = -2.93, p < 0.01; d = 0.9$) in comparison to the SPU during the eccentric phase.

EMGPEAK for the KPU was significantly lower ($p < 0.05; d = 1.2$) in comparison to the SPU during the concentric phase. For the eccentric phase LD EMGPEAK for the SPU was greater than both the KPU ($p < 0.01; d = 1.5$) and the BPU ($p < 0.01; d = 1.4$).

Significant differences were also reported for LD EMGPEAK during both the concentric ($F(1.92, 19.16) = 5.55, p < 0.05$) and eccentric phase ($F(1.79, 17.90) = 14.73, p < 0.01$). LD

No significant differences were found for IF EMGPEAK during the concentric phase ($F(1.72, 17.17) = 2.27, p = 0.14$). However, a significant difference in IF EMGPEAK during the eccentric phase was reported ($F(1.96, 19.85) = 8.20, p < 0.01$). IF EMGPEAK for the BPU was significantly higher in comparison both to the KPU ($p < 0.05; d = 0.9$) and SPU ($p < 0.05; d = 1.2$). No other significant differences were found.

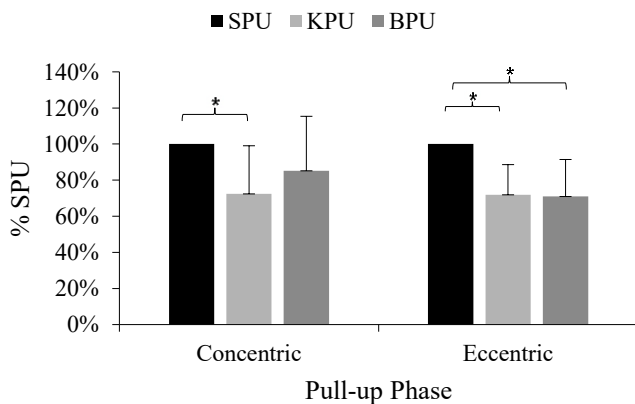


Figure 7: EMGPEAK as % SPU for the latissimus dorsi across all three variations. Values are given as mean \pm SD. * indicates significant difference ($p < 0.05$).

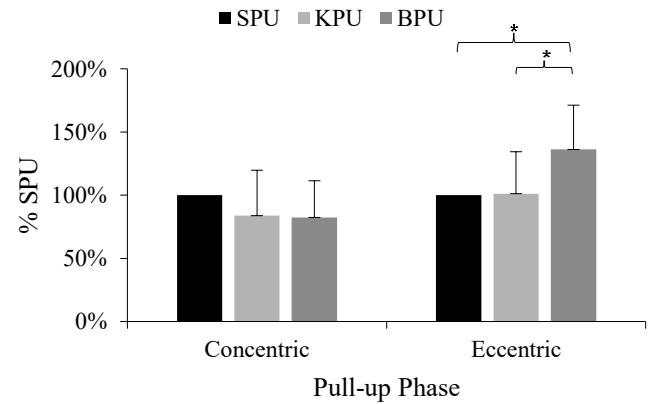


Figure 8: EMGPEAK as % SPU for the infraspinatus across all three variations. Values are given as mean \pm SD. * indicates significant difference ($p < 0.05$).

4. Discussion

The purpose of this study was to provide insight into the KPU and BPU in comparison to the SPU. Previous research had shown lower levels of upper body muscle activation in the KPU (Dinunzio et al., 2017; 2018) in comparison to the SPU. However, no research in this area exists for BPU and it is unknown how muscle activation may differ between the concentric and eccentric phases during all three pull-up variations. The results of this study confirm that both styles of kipping increase lower body muscle activation and decrease upper body activation in comparison to the SPU. It is important to point out that muscle activation was compared to levels shown in the SPU and not a true lower body MVC. Therefore, it is not possible to determine whether a true meaningful stimulus was produced in the lower body. Our findings also suggest that, due to the different style of kip, both the KPU and BPU display different muscle activations. Further, these muscle activation patterns are dependent on the phase of the pull-up. This confirms the hypothesis of this study.

Confirming the findings from Snarr et al. (2018) an increase in lower body muscle activation was found in this study between the KPU and BPU in comparison to the SPU. While significant increases in muscle activation were found in all three lower body muscles, only the RF had elevated levels of activation across both phases in both the KPU and BPU. This increase in activation of the RF is expected, due to the lower body swing when moving between the hollow and arch position (Figure 1b-d and Figure 2b-e) in each style of pull-up. Similar findings were found by Dinunzio et al. (2018) who found the tensor fasciae latae (TFL) and iliopsoas (IL) muscles elicited greater levels of muscle activation during a KPU in comparison to the SPU. As the TFL, IL, and RF all contribute to flexion of the hip (Jiroumaru, Kurihara, & Isaka, 2014), this confirms the role of the hip flexors in generating momentum during the KPU and BPU.

As hypothesized, when absolute load (in this case body mass) is constant, the generation of momentum from the lower limbs during the BPU and KPU resulted in reduced upper limb muscle activation in comparison to the SPU. Both the BB and LD showed significant decreases in muscle activation during the BPU and KPU, though no differences in muscle activation were found between exercises for the IF. These findings compare with Dinunzio, Van Scoy, Porter, Cordice and McCulloch, (2017) who found a reduction in activation of the BB and LD ranging from 5 – 15% MVIC during the KPU. In a more recent study Dinunzio et al. (2018), highlighted the BB as the only upper body muscle to demonstrate reduced muscle activation during the KPU when compared to the SPU. Momentum is generated using the lower limb during the kip, which aids the pulling action from the upper limbs during the concentric phase of the exercise, requiring less muscular effort from muscles such as the BB and LD. This appears to not be true for the BB during the eccentric phase of the pull-up as the style of kip may also influence upper limb muscle activation. As supported by the literature (Dinunzio et al., 2018), BB muscle activation is reduced for the KPU during both the concentric and eccentric phases in comparison to the SPU. However, BB muscle activation during the eccentric phase of the BPU is significantly higher in comparison to both the KPU and, though not significant, the SPU (Figure 4). This is likely due to the body position during the eccentric phase. During the KPU, the athlete moves into a hollowed position (Figure 1e) whereas during

the BPU the athlete moves into an arched position (Figure 2e). The arched position likely requires a large contribution from the BB to eccentrically control the lowering of the body, thus the higher BB activation during this phase. This highlights that lower limb momentum does reduce upper body muscle activation during the KPU and BPU, however, the different styles in kipping also influences upper limb muscle activations, most notably during the eccentric phase.

Further analysis of the results of this study also highlight the different lower limb muscle activations seen between the KPU and the BPU. During the concentric phase of the KPU the athlete pulls into an arched position before swinging into a hollowed position as momentum moves the body upwards. In comparison, during the BPU the athlete does not pull into an arched position until the eccentric phase. This would explain why GM activation is significantly greater during the concentric phase of the KPU, and the eccentric phase of the BPU. Further, though not as clear, both the RA and RF show similar activation patterns between exercises. Pulling into the arch position allows these muscles to lengthen, which increases muscle activation and generates the necessary muscle force to swing the legs through, creating momentum for the pulling phase of the exercise. This highlights that both kipping strategies for the KPU and BPU are similar but occur during different phases of the exercises, which alters lower limb muscle activation patterns.

The current study expressed muscle activation as a % of SPU. However, Snarr et al. (2018) presented activation as % MVIC, whereas Dinunzio et al. (2017) presented absolute values with SPU data being subtracted from the KPU and then expressed as a % MVIC. Therefore, the method in which muscle activation is presented differs between studies, which makes the comparison of findings difficult. No kinematic data was recorded in the sagittal plane for this study. As a result, differences in the arched and hollow body positions used in both the KPU and BPU in this study are not objectively known. Further, the participants were allowed to perform all three exercises at a self-selected speed. Participants being able to get into a greater arched position at a greater speed may increase the activation of certain muscles and influenced the results of this study. To minimise this, we recruited participants who have a similar training history with all three exercises. However, having this additional kinematic data would help provide insight to the muscle activation patterns when performing these exercises and further understand the differences between the KPU and BPU.

Conflict of Interest

The authors declare no conflict of interests.

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