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Kinesiotaping enhances the rate of force development but not the neuromuscular efficiency of physically active young men

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Key-words: muscle strength; knee; physical therapy.

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Abstract

**Introduction:** Investigations on the effects of KT on human performance have been increasing in the last few years. However, there is a paucity of studies investigating its effects on neuromuscular efficiency (NME) and rate of force development (RFD).

**Objective:** To evaluate the NME and RFD of the soleus and gastrocnemius muscles in physically active individuals under KT application. **Methods:** Twenty young males (79.7 ± 8.2 kg; 1.78 ± 0.05 m; 24.7 ± 4.4 years) performed three conditions in a randomized order: 1) Baseline (BL, no tape); 2) Activation (ACTI\textsubscript{KT}, tape for muscle activation); and 3) Inhibition (INHI\textsubscript{KT}, tape for muscle inhibition). The tape was applied along the lateral and medial border of gastrocnemius with 30% tension for 48 hr. Peak torque (PT), RFD and NME were measured at BL and 48 hr after ACTI\textsubscript{KT} and INHI\textsubscript{KT} by performing a maximum isometric contraction. **Results:** The RFD was significantly higher in ACTI\textsubscript{KT} compared to BL at 0-30 (\(p=0.010\)), 0-50 (\(p=0.008\)) and 0-100ms (\(p=0.007\)). The PT and NME did not differ among conditions (\(p>0.05\)). **Conclusion:** KT applied for muscle activation yielded a higher RFD during the initial phase of the muscle contraction. However, KT has no enhancement effect on NME and peak torque.

**Key words:** muscle strength; knee; physical therapy.
Introduction

The Kinesiotaping (KT) is a method based on the concept that both the skin and subcutaneous tissues can be mechanically stimulated under the use of an elastic tape applied with a specific direction and tension level (Kase et al., 2003). Investigations on the effects of KT on human performance and rehabilitation have increased in the last few years (Chang H-Y et al., 2012, de Almeida Lins et al., 2013, Fratocchi et al., 2013, Howe et al., 2015, Lumbroso et al., 2014, Mostert-Wentzel et al., 2012). Effects of KT on muscle strength (Fratocchi, Di Mattia, 2013, Zanchet and Del Vecchio, 2013), muscle activity (Slupik et al., 2006) and jump performance (Aktas and Baltaci, 2011) have been reported. However, recent systematic reviews pointed out that the scientific evidence of the KT is still inconclusive (Csapo and Alegre, 2015, Williams et al., 2012). Specifically for muscle strength effects, Csapo and Alegre (2015) demonstrated that the majority of recent KT studies had a substantial heterogeneity and low methodological quality, leading to inconclusive effects of the KT on muscle strength. Notwithstanding, there is a widespread use of the KT in clinical and sport research (Cai et al., 2015, Firth et al., 2010, Huang et al., 2011, Morris et al., 2013).

It has been postulated that KT can either “facilitate” or “inhibit” muscle function through different levels of mechanoreceptors activation (Kase, Wallis, 2003). Anterior cruciate ligament injury (Chaves et al., 2012) and exercise-induced muscle fatigue (Han and Lee, 2014) inflict proprioceptive impairments, which could change the pattern of motor unit recruitment and, consequently, decrease muscle strength and power (Chaves, Marques, 2012). Subjects with proprioceptive deficits have shown a positive response to the KT method (Han and Lee, 2014). An enhancement of muscle strength in subjects who used the tape on the quadriceps muscle has also been reported (Vithoulka et al., 2010). These effects might be ascribed to tactile stimulations that seems to interact with the kinetic control at the central nervous system (Vithoulka,
Beneka, 2010) and a concentric pull on the fascia, which may induce increased muscle contractions (Williams, Whatman, 2012). Based on the aforementioned effects of the KT, it is possible to assume that this method could alter the recruitment pattern of motor units. Hence, the KT could influence an important variable for athletic performance such as the rate of force development – RFD (i.e., the rate of rise in contractile force exerted in the early phase of muscle contraction) (Aagaard et al., 2002). However, there is a paucity of studies investigating the effect of KT on muscular efficiency and contractile capacity, and further studies are warranted.

The neuromuscular efficiency (NME) is another relevant parameter to be investigated, as it represents the muscle responsiveness to a neural excitation (Deschenes et al., 2002) and is based on the relationship between the force generated by a muscle and its electromyographic activity. Hence, the NME can be interpreted as the ability to produce higher levels of strength within a lesser muscle activation (Deschenes, Giles, 2002).

Although this issue is not explored in KT studies, both the RFD and NME are important parameters related to muscle performance and neuromuscular capability, especially for sports movements (i.e., throw, sprint and jump) (Hernández-Davó and Sabido, 2014). Additionally, these variables have been considered more important than muscular strength during assessments comprising explosive movements. Consequently, investigating the effects of KT application on RFD and NME may improve the understanding of its effectiveness on neuromuscular performance. Therefore, the aim of the present study was to evaluate the NME and RFD of the soleus and gastrocnemius muscles in physically active individuals under different conditions of KT application (i.e., muscle activation, and muscle inhibition). It was hypothesized that the KT for muscle activation would enhance both the NME and RFD during a maximal voluntary isometric contraction.
Method

Participants

Twenty young and physically active males (79.7 ± 8.2 kg; 1.78 ± 0.05 m; 24.7 ± 4.4 years) participated in the study. The sample size was determined a priori (GPower version 3.1.2), considering the following design specification for the studied variables (RFD and NME): statistical power of 80%, α value of 5% (α = 0.05; Type I error), to detect moderate effect size (f=0.5), test family F test and statistical test ANOVA for repeated measures. Participants were recruited through posters allocated at strategic points of the university campus and by word of mouth. The body mass and height of the participants were measured on the first visit to the Laboratory.

All participants answered the International Physical Activity Questionnaire (IPAQ, short version) (Hagströmer et al., 2006). The inclusion criteria were: a) healthy and physically active subjects (i.e., regular physical exercise during the six months); b) age between 18 and 35 years; c) height between 1.65 m and 1.95 m; d) absence of pain or musculoskeletal symptoms and injuries of the lower limbs in the last 6 months prior to the research. Participants were excluded if they had sensitive skin or tissue scars on the leg region where the KT would be applied. Individuals who met the criteria were invited to participate by signing the Informed Consent. The study was approved by the Institutional Review Board (protocol n. 31879014.4.0000.0030).

Experimental design

The participants attended the laboratory on three different occasions, with an interval of 48 hr between each visit. Subjects performed three experimental conditions on each visit: 1) Baseline - no KT application (BL); 2) Activation - KT applied for muscle activation (ACTIKT); and 3) Inhibition - KT applied for muscle inhibition (INHIKT). In order to avoid possible effects of the tape under the conditions of activation or inhibition, the BL condition was always carried out in the first visit. The order of both ACTIKT and
INHI\textsubscript{KT} experimental conditions were randomized for all subjects (www.randomization.com). Participants were unaware of the condition under study. For both ACTI\textsubscript{KT} and INHI\textsubscript{KT} experimental conditions, the subjects were instructed to remain with the tape, continuously, for 48 hr. Peak torque, RFD and NME were measured at BL and 48 hr after ACTI\textsubscript{KT} and INHI\textsubscript{KT} placement by performing two maximum isometric voluntary contraction of ankle planatarflexion (Figure 1). The interval between the first and the second visit to the laboratory was 48 hr and 96 hr from the second to the third visit. Subjects were asked to visit the laboratory always at the same time of day to avoid circadian influences. They were also not allowed to perform any vigorous physical activities or unusual exercise during the experiment period.

\textbf{Figure 1 Here}

\textit{Kinesiotaping application}

The elastic tape in the two experimental conditions (ACTI\textsubscript{KT} and INHI\textsubscript{KT}) was applied using the protocol proposed by Kase, Wallis (2003). KT was applied with subjects lying down in prone position with the knee fully extended and feet out the examination table. Two wide strips (5 cm) in an 'I' shape was used, both applied along the lateral and medial border of gastrocnemius (Figure 2). The therapeutic area (muscle area subjected to the tape tension) was defined as the distance between point "A", located 5 cm below the knee joint interline (rear region), and the point "B", located 7 cm above the lateral malleolus, on the initial portion of the triceps surae tendon. Two attachment points without tension were adopted in order to apply the KT. The upper attachment point was 5 cm long and the bottom had 20 cm, covering the whole calcaneal tendon until the bottom of the heel (Figure 2). In order to standardize the application of the elastic tape and improve the reliability, the present study adopted a 30% tape length tension of tape defined by the following equation:
Length = (DIST A → B x 0.7) + 20 cm + 5 cm

DIST A → B: Distance between points A and B, in centimeters.

Activation and inhibition techniques differed by how the tape was applied to the skin. For the activation technique, the tape followed a proximal to distal tension application (Kase, Wallis, 2003), with the tape being tensioned from the point ‘A’ line (5 cm below the posterior popliteal fossa) up to the point ‘B’ line (7 cm above the lateral malleolus) (Figure 2). For the inhibition protocol, the application followed the same attachment points and therapeutic area, differing by a distal to proximal tension application, according to Kase, Wallis (2003). The area of application was shaved when needed. The same investigator, certified for the KT method (Certified KT1/KT2), applied the tape.

Figure 2 here

Surface electromyography (EMG)

The electromyographic activity of the soleus muscle was recorded during a maximal voluntary isometric contraction (MVIC) by a surface electromyography system (Viking EMG system; Nicolet, Natus Medical Incorporated), with a sample rate of 2000 Hz. The EMG has a common mode rejection ratio of >110dB, input impedance of 1000 ohms and a band-pass filter from 1 to 500 Hz. The volunteers were instructed to lie down on a bench for the EMG electrodes placement. The simple differential active electrodes had polyethylene foam with hypoallergenic adhesive, bipolar contact of Ag/AgCl and a between poles distance of 20 mm. The electrodes were placed 1 cm below the junction of the two heads of the gastrocnemius muscle, above the aponeurosis of the soleus muscle, with a distance of 2 cm between them, according to
Burke (1997) (Figure 3). Before placing the electrodes, the area was shaved and lightly abraded with 70% alcohol. The reference electrode was attached to the bony prominence of the radius and ulna styloid process. Placement of the electrodes was identified on the first day of testing and an indelible pen mark was made on the skin to ensure the same position was used on subsequent days.

Maximum voluntary isometric contraction (MVIC)

For the MVIC, subjects were placed on an isokinetic dynamometer (Biodex System 3, Biodex Medical, Shirley, NY) to evaluate the peak torque and the rate of force development (RFD). After the EMG procedures, on each visit, all subjects performed the MVIC of the gastrocnemius, with their trunk positioned at 70º (seat inclination), hip at 90º and their knee joint positioned at 30º (0º being the full extension of the knee) - Figure 3. This position was adopted with the purpose of prevent undesired influences of knee movements. The MVIC was performed with three sets of 5 s for ankle plantar flexion, with a rest interval of 1 min between sets. The rotation axis of the isokinetic dynamometer arm was aligned with the lateral malleolus of the subject. The contraction angle was set in the neutral position (0º) and the tests were conducted only in the dominant limb (leg used to kick a ball). The contralateral limb was held under the support of a coupled support rod in the isokinetic chair, in order to prevent a leg compression. The chair position was recorded on the first visit and replicated in the subsequent visits, to ensure the positioning reliability. The procedures were performed by the same investigator.

**Figure 3 Here**
Signal processing

For the calculation of RFD and peak torque, the dynamometer signals were processed using Matlab (version 7.0, Math Works, Inc.). For the RFD calculation, the highest peak torque achieved during each MVIC was used for analysis purposes. The RFD was derived as the average of the moment-time curve slope (Δmoment/Δtime) at the intervals 0-30ms, 0-50ms, 0-100ms and 0-200 ms, during the initial phase of muscle contraction.

The root mean square (RMS) of the EMG signal was calculated by the Nicoleit Viking Quest software (Care Fusion, version 8.1) considering the central 3 s portion of the signal. After determining the peak torque of the MVIC and the RMS, the NME was calculated by the following equation proposed by Arabadzhiev et al. (2010):

\[
NME = \frac{PT}{RMS}
\]

In which:
PT: Peak torque, in N.m
RMS: Root mean square, in μV

Statistical analysis

Statistical analysis was performed with the SPSS software, version 22.0. Normality assumptions were confirmed by the Shapiro-Wilk test for the PT and RFD variables, and data are presented as mean (standard deviation). An ANOVA with repeated measures and Bonferroni post hoc was adopted in order to verify differences in PT and RFD (0-30; 0-50, 0-100 and 0-200 ms) among the three conditions (BL, ACTI_{KT} and INHI_{KT}). The effect size (Cohen’s d) was determined based on Rhea (2004) and classified as trivial (d<0.35); small (d> 0.35 and <0.80); moderate (d≥0.80 and <1.50) and large (d≥1.5). The significance was set at 5% (P<0.05).
Considering that the normality assumptions of the NME variable was not confirmed by the Shapiro-Wilk test, the Friedman test was applied in order to verify the differences in the NME values among the three conditions. In case of significant differences, a Wilcoxon test with post-hoc multiple comparisons were performed. To prevent the accumulation of the Type I error in the multiple comparisons, the significance of 5% ($\alpha=0.05$) was divided by three comparisons (BL x ACTIkT; BL x INHIkT and ACTIkT x INHIkT). Therefore the significance adopted in post hoc test was 1.6% ($P \leq 0.016$). For the effect size of the nonparametric data, the values of “z-score” Wilcoxon’s multiple comparison test was converted to a size of the estimated effect ($r$) using the formula:

$$r = \frac{Z}{\sqrt{N}}$$

In which:
- $Z =$ Z-score
- $N =$ number of total observations

Results

RFD was higher in ACTIkT condition when compared to the BL condition for 0-30ms ($p=0.010$), 0-50ms ($p=0.008$) and 0-100 ms ($p=0.007$) time intervals (Table 1). Moderate effect sizes were found for comparisons between ACTIkT and BL in 0-30, 0-50 and 0-100ms intervals. However, there were no differences in RFD for the other comparisons (INHIkT vs. BL, and ACTIkT vs. INHIkT, $p>0.05$). Trivial and small effect sizes were found for comparisons between INHIkT and BL, and ACTIkT vs. INHIkT. In addition, there were no differences in RFD within each condition (BL: $p=0.680$; ACTIkT: $p=0.112$; and INHIkT: $p=0.216$).

Peak torque and NME values are presented in Table 2. Regarding peak torque, there were no significant differences among conditions ($p=0.210$). Moreover, NME did not differ among conditions ($p=0.271$). Trivial effect sizes were found for all comparisons.
Table 1 Here

Table 2 Here

Discussion

The purpose of the present study was to evaluate the neuromuscular efficiency and rate of force development of the soleus and gastrocnemius muscles in physically active individuals. Our initial hypothesis was partially confirmed, that KT application for muscle activation (ACTIKT) caused a higher RFD in comparison to baseline condition (no tape application). However, KT application did not affect peak torque measurements and neuromuscular efficiency.

The present study demonstrated significant and higher RFD values for the ACTIKT during the intervals of 0-30, 0-50 and 0-100 ms when compared to the BL. According to Aagaard, Simonsen (2002), the RFD represents the force development exerted during the initial stages of the muscle contraction. Thus, the RFD has been considered an important functional parameter, and one of the main physical capacity due to its high correlation with performance in several sports activities (Aagaard, Simonsen, 2002, Hernández-Davó and Sabido, 2014). It is also noteworthy that the majority of muscles requires periods equal or greater than 300 ms to develop their maximum strength, demonstrating that the RFD seems to be more related to muscle power than the maximum force capacity (Aagaard, Simonsen, 2002). Our findings are not in agreement to those reported by Serra et al. (2015). They evaluated the KT effects on knee extension force in soccer players, and found no significant differences in the RFD between KT and a placebo group (with Micropore tape). The authors speculated that KT may have beneficial effects only for patients with motion disorders and pain, unlike healthy athletes with a normal strength condition. It is important to note
that in the Serra, Vieira (2015) study the KT was applied over the quadriceps muscle of one limb and the Micropore tape was applied at the same time on the contralateral limb, i.e., the authors used the subjects’ contralateral leg as control. Interestingly, Carroll et al. (2006), reported a contralateral strength effect during an unilateral resistance exercise. Thus, the findings by Serra and Colleagues (Serra, Vieira, 2015) should be interpreted with caution, considering that the force measurements of the assessed limb may have been influenced by the contralateral one. In addition, a possible methodological issue regarding KT application remains as neither tape tension nor taping technique was standardized in Serra, Vieira (2015), whereas in the present study, an equation to standardize taping application and tension was adopted. Moreover, the RFD can be influenced by several factors such as the distribution of muscle fibers, the magnitude of motoneuron activation on the onset of muscle contraction, the firing rate and recruitment pattern of motor units (Corvino et al., 2009). This means that with requirements for a greater force and/or faster muscle contraction, high-threshold fatigable motor units will be recruited (fast-twitch muscle fibers IIb) (Burke, 1997, Komi and Commission, 1993). It can be surmised that a reduction in the threshold of the later recruited motoneurons induced by a stimulation of cutaneous mechanoreceptors after the ACTI KT application, lead to changes in the pattern of recruitment of motor units, as suggested elsewhere (Wong et al., 2012, Yeung et al., 2015). Further studies are necessary to confirm this possibility.

Our study failed to identify significant KT inhibition effects on the RFD measurements when compared to the BL and ACTI KT. This finding was unexpected considering the underlying assumptions of the KT method applied for muscle inhibition, which could be achieved by stretching the Golgi tendon organ at the distal end of the muscle (Cai, Au, 2015, Kase, Wallis, 2003). For instance, a previous study (Cai, Au, 2015) compared the neuromuscular activity of the wrist extensor muscles and the grip strength between facilitatory, inhibitory and no Kinesiotaping application in healthy adults. The authors found no significant inhibitory effects for grip strength and wrist
muscles RMS, which they attributed to a KT effect that is mainly anecdotal and only clinically relevant (Cai, Au, 2015). Nevertheless, we found a significant RFD effect for the ACTI\textsubscript{KT} condition. From a practical standpoint, it is worthy of note that the specific effects and mechanisms of KT are still unknown (Csapo and Alegre, 2015, Gómez-Soriano et al., 2014). Additionally, to the best of our knowledge, there is no plausible theory or principle that could explain the “inversion effect” of the elastic tape (i.e., application from the muscle origin to insertion and vice-versa). Hence, further studies are recommended in order to better understand the effects and mechanisms of the elastic tape direction, in different populations (with and without dysfunctions).

According to Komi and Commission (1993), in a specific muscle group with a main histochemical characteristic composed by type I fibers, the frequency of firing rate has a more prominent role in modulating strength and power. On the other hand, for muscles composed by both type I and type II fibers, the recruitment pattern of their motor units seems to exert a greater influence on the ability to produce power at levels above 40-50\% of its maximal voluntary contraction (Komi and Commission, 1993). Moritani et al. (1991) reported a preferential activation of fast fibers in the medial gastrocnemius muscle compared to the soleus muscle (which presents larger amount of slow fibers), with an increased strength during vertical jumps. Hence, as we did not monitor the EMG activity of the lateral and medial gastrocnemius, this could explain why the neuromuscular efficiency was not influenced by the KT. Since the gastrocnemius muscles are the major contributors to the maximum plantar flexion force capacity, it is possible to assume that the KT would have influenced their NME findings.

With respect to muscle strength, the present results are in agreement to those of Huang, Hsieh (2011) who investigated the effects of the KT on the soleus muscle and anterior tibialis during a maximum vertical jump test. Although an increased vertical reaction force was found with the use of KT, the jump height decreased, and there was no significant difference in the EMG activity of the medial gastrocnemius, tibialis anterior and soleus muscle in either group (KT and placebo). Similarly, de Almeida
Lins, Neto (2013) concluded that the KT had no enhancement effect on the quadriceps muscle strength and electromyographic activity of the vastus lateralis muscle in healthy women. Morris, Jones (2013) postulated that the KT has immediate increases in muscle strength by producing a concentric pull on the fascia. These effects may be responsible to an increased muscle activity and enhanced muscle alignment provided by the taping (Morris, Jones, 2013). However, the present study corroborates previous research (Chang H-Y, Wang C-H, 2012, Wong, Cheung, 2012) that did not find any effects between KT and muscle force production. The main theory concerning the absence of significant results was that the tactile input provided by KT may not be strong enough to modulate muscle strength of healthy individuals (Wong, Cheung, 2012).

It is suggested that an accurate electromyographic analysis of the gastrocnemius (perhaps, through the use of refined techniques of signal processing) could provide a better understanding of the changes observed in the RFD, considering its prime mover function and a higher proportion of fast motor units compared to the soleus muscle (Gollnick et al., 1974). Additionally, it is recommended that future studies adopt the measurement of the H reflex or neural drive during muscle contraction, which can be used to assess the response of the nervous system to various therapeutic modalities and to better understand the tape direction effects.

Conclusion

Our findings demonstrated that the KT applied for muscle activation yielded a higher rate of force development during the initial phase of the muscle contraction when compared to no tape condition. Further studies on this topic are necessary in order to better understand the effect of KT application mainly on sports activities and symptomatic population. Other population, such as women and elderly, should also be evaluated.
Acknowledgement

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References


Komi PV, Commission IM. Strength and power in sport: Blackwell scientific publications; 1993.


Table 1. Rate of force development (RFD, in N.m.s\(^{-1}\)). Values are presented as mean (standard deviation), with the mean difference (MD) and the 95% confidence interval (95% CI) of the comparisons.

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<th>INIB(_{KT})</th>
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ES = Effect Size; ACTI\(_{KT}\): Activation KT; INIB\(_{KT}\): Inhibition KT; BL: Baseline

Significant difference with the BL: *\(p=0.010\); **\(p=0.008\); †\(p=0.007\)
Table 2. Peak torque (in N.m) and Neuromuscular efficiency (NME) values. PT values are presented as mean (standard deviation), with the mean difference (MD) and the 95% confidence interval (95% CI) of the comparisons. NME Values presented as median and quartiles (Q25% and Q75%).

<table>
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<th>INHIKT</th>
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<td>0.16</td>
<td>1.99 [-19.44; 23.43]</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(37.40)</td>
<td>(46.50)</td>
<td></td>
<td></td>
<td>(39.24)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>BL</th>
<th>ACTIKT</th>
<th>INHIKT</th>
<th>ACTIKT x BL</th>
<th>INHIKT x BL</th>
<th>INHIKT x ACTIKT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>(Q25; Q75)</td>
<td>Median</td>
<td>(Q25; Q75)</td>
<td>Median</td>
<td>(Q25; Q75)</td>
<td>r</td>
</tr>
<tr>
<td></td>
<td>0.49 (0.34; 0.74)</td>
<td>0.54 (0.32; 0.71)</td>
<td>0.58 (0.34; 1.04)</td>
<td>-0.19</td>
<td>-0.06</td>
<td>-0.28</td>
</tr>
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</table>

ES = Effect Size; ACTIKT: Activation KT; INHIKT: Inhibition KT; BL: Baseline; r: size of the estimated effect
Captions to illustrations:

**Figure 1**: Flowchart with the procedures adopted in the present study. The order of ACTI$_{KT}$ and INHI$_{KT}$ conditions were randomized for each subject. (BL: Baseline, without the tape; ACTI$_{KT}$: Kinesiotaping for activation; INHI$_{KT}$: Kinesiotaping for inhibition; KT: Kinesiotaping; RFD: rate of force development; NME: Neuromuscular efficiency).

**Figure 2**: Illustration of the KT application and EMG electrodes placement.

**Figure 3**: Illustration of the isokinetic dynamometer’s procedures.
Figure 1.

Day 1: BL
- Informed Consent;
- Anthropometric assessment;
- KT application - Baseline assessment:
  - Peak torque, RFD and NME

Day 2:
- KT application (ACTI\textsubscript{KT} or INHI\textsubscript{KT});
  - after 48h: Peak torque, RFD and NME assessment

Day 3:
- KT application (ACTI\textsubscript{KT} or INHI\textsubscript{KT});
  - after 48h: Peak torque, RFD and NME assessment
Figure 2.

- **Point A**
- **Point B**
- **Area under tension**
- **EMG Electrode Placement**
- **Attachment point**

**Figure 2.**
Figure 3. Illustration of the isokinetic dynamometer’s procedures.
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