DIFFERENCE BETWEEN MUSCLE ACTIVITIES DURING JUMPING MOTION IN DESCENT AND ASCENT PHASES ON A TRAMPOLINE

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Abstract
Trampoline bounces are performed on a bed of a jumping surface that is stretched over the trampoline apparatus. The jumping motion is divided into a descent phase, i.e., from the landing to the maximum depth, and an ascent phase, from the maximum depth to the takeoff. Most studies on muscle activity during jumping have investigated muscle activity during the same phase between groups or between landing and release; however, no studies have investigated muscle activity between phases. Therefore, this study aimed to investigate muscle activity during the descent and ascent phases and obtain basic data on the jumping motion. For the trials, participants were instructed to perform 15 consecutive jumps on the trampoline bed from a standing still position, as high as possible, straight and straight up in the center of the trampoline bed. The muscle activities of the rectus femoris, tibialis anterior, and lateral gastrocnemius revealed significant increases and larger effect sizes in the descent phase than in the ascent phase (p < 0.01). The muscle activities of the sternocleidomastoid, trapezius, and biceps femoris demonstrated significant increases and medium effect sizes in the descent phase in contrast to the ascent phase (p < 0.01). Pushing down the bed by the muscular activity of the lower extremities is most pursued in the descent phase. Then, participants maintain a straight vertical posture for the body to receive the rebound force from the maximum depth of the bed. This suggests that the sternocleidomastoid and trapezius muscles were significantly active in controlling the head position. A high jump is achieved by pushing the bed down for a deep descent and maintaining a straight posture at the maximum depth. The elastic bed is similar to an Open Kinetic Chain in the descent phase because the load incrementally increases, and to a Closed Kinetic Chain in the ascent phase because the load begins at the maximum depth of the bed. Separating the elements of the jumping motion required in the descent and ascent phases is important in athletic training.

Keywords: trampoline gymnastics, trampoline bed, electromyogram, Open Kinetic Chain, Closed Kinetic Chain.
INTRODUCTION

The trampoline event, which was officially adopted for the 2000 Olympics, is judged by performing a continuous series of 10 different movements. Four main scoring methods were used, including execution, horizontal displacement, time of flight, and difficulty (2022–2024 Code of Points Trampoline Gymnastics, 2021). These four methods of scoring are determined by jumping out from the trampoline apparatus. Trampoline gymnasts find it difficult to change direction or body position significantly once they jump into the air in gravity. Therefore, jumping motion is important for trampoline gymnasts. Song et al. (2011, 2013) investigated muscle activity during jumping motion and reported that the active muscles and the landing position of muscle activity differed depending on the landing position of the trampoline’s jumping surface (bed). Muscle activity was greatest during the jumping performed in the center of the bed, with greater activity in the gastrocnemius and tibialis anterior muscles. Athletes adapt to the hardness of the bed and force with good coordination. A comparison between elite and non-elite groups revealed significant differences in rectus femoris and biceps femoris muscle activity (Matsushima et al., 2017). A study examining horizontal movement bounce revealed a high correlation between the centrally made jumps and gastrocnemius activity (Matsushima et al., 2018a). The gastrocnemius muscle activity could be identified as an eccentric contraction. Several studies were conducted on muscle activity in the jumping motion on the trampoline.

The 4,260 mm (length) × 2,130 mm (width) bed produces a large vertical deflection between landing and takeoff due to the jumping motion. Jumping on the bed consists of two phases: from landing to the maximum depth (descent phase) and from the maximum depth to the takeoff (ascent phase). The distance to the maximum depth where the bed extended the longest was approximately 0.8 m, and the duration of the descent and ascent phases was approximately 0.15 s each (David, 2015; David et al. 2012; Ito et al., 2000; Jingguang et al., 2020; Martin, 2001; Matsushima, 2021; Wojciech and Adam, 2001). A study that used two variables to indicate an index of jumping quality, including ascent phase time and deflection distance of the bed, revealed that jumping with a longer deflection distance of the bed and shorter time was better than jumping with a longer time of flight (Matsushima, 2021). The jumping ability to obtain long deflection distances and short times on the bed was discussed. Additionally, this study provided an index of relative jumping motion by determining the distance of bed deflection per body weight. Trampoline gymnasts receive different loads from the bed depending on the jumping phase because of the great elasticity of the bed. The load increases as the bed deflection distance increases in the descent phase; the load is greatest at the maximum depth, and least toward the takeoff in the ascent phase (Martin, 2001; Matsushima et al., 2018b, 2018c; Matsushima, 2023).

The required elements for jumping motion are different for the descent and the ascent phases on the bed. However, many previous studies compared different groups in the same phase or analyzed muscle activity from landing to takeoff without phase separation. No study has been
conducted on muscle activity concerning the two phases. Therefore, this study aimed to obtain basic data by comparing the muscle activities of the trampoline jumping motion in both phases on the bed. Participants were selected from individuals registered with the Japan Gymnastics Association who had competed in the All Japan Trampoline Championships.

METHODS

Participants included ten trampoline athletes, 5 females and 5 males, registered with the Japan Gymnastics Association who had competed in the All Japan Trampoline Championships (age: 19.5 ± 1.6 years, height: 163.9 ± 6.7 cm, weight: 58.5 ± 8.2 kg, athletic career: 7.9 ± 4.2 years). The details of the experiment were fully explained to the participants before the experiment using the protocol of the Mukogawa Women’s University research ethics review committee (approval number No. 13-52). They were asked to provide their written consent.

The trampoline apparatus used in the experiment was a 4 × 4 Euro trampoline (5.20 m long, 3.05 m wide, and 1.15 m high) manufactured by EUROTRAMP, a company approved by the International Gymnastics Federation. For the trials, after a sufficient warm-up period, participants were instructed to perform 15 consecutive jumps on the trampoline bed from a standing still position, as high as possible, straight and straight up in the center of the trampoline bed.

The isometric maximal voluntary contraction (MVC) of each muscle was measured by manual muscle testing after each experiment (Hislop and Montgomery, 2002). Participants were instructed to exert force using manual resistance by the examiner to incrementally increase the contraction force for >3 s and then hold the MVC for 2 s. MVC was used for a total of 1.0 s, including 0.5 s before and after the maximum amplitude. Eight muscles were measured in total: sternocleidomastoid (SCM), trapezius upper part (TR), rectus abdominis (RA), erector spinae (L4 level) (ES), rectus femoris (RF), biceps femoris long head (BF), tibialis anterior (TA), and lateral gastrocnemius (LG). The SCM was contracted by applying manual resistance to the frontal part of the head while the neck was flexed forward. The TR was contracted by applying manual resistance to the occiput while flexing the neck backward. The RF was contracted by sitting on a chair with the hip joint at 90 deg, and knee joint extension was performed while manual resistance was applied to the front surface of the lower leg. The BF was contracted in the prone position, and the knee joint was flexed with manual resistance applied to the posterior lower leg. The TA contraction was performed in a seated position with ankle joint dorsiflexion while manual resistance was applied to the dorsum of the foot. The LG contraction was measured by letting the patient perform ankle joint plantar flexion in a unilateral standing position. Maximal contractions of the ES and RA muscles followed the method of Vera-Garcia et al. (2010). The ES was contracted by holding the legs down in the prone position and applying manual resistance to the posterior back while the trunk was flexed backward. The RA was contracted by holding the legs down in the supine position and applying manual resistance to the shoulder while the trunk was flexed forward.

A compact tension/compression load cell (KYOWA ELECTRONIC INSTRUMENTS CO., LTD.: LUX-B-2KN-ID) was attached between the 17th
spring (counting from the right end) and the frame at the center of the trampoline side. The landing, i.e., where the subject touched the trampoline bed, the maximum depth - where the trampoline bed extended maximally descent, and the takeoff - where the subject left the trampoline bed, were determined from the load cell output using analysis software (KISSEI COMTEC CO., LTD.: BIMUTAS II) (Figure 1). The descent phase was defined as the phase between the landing and maximum depth, and the ascent phase between the maximum depth and takeoff. The sampling frequency was set to 1000 Hz, and the data was recorded on a personal computer (PC).

The skin was shaved and prepared with fine sandpaper and ethanol to lower its impedance. According to Aldo (Aldo and Hugh, 2005), wireless electrodes were placed and secured with surgical tape to stabilize them and minimize artifacts. A wireless electrocardiograph (multi-channel telemeter system WEB-7000, Nihon Kohden CO., LTD, Japan) was used to record the signals from each participant. The experiment derived electromyography (EMG) with a 1000Hz sampling frequency. Data was then transferred from the memory card to a PC and synchronized with the load cell signal.

Of the 15 trial jumps, 9 jumps, 7th to 15th, were included in the analysis. The collected EMG data during each action were converted through a band-pass filter (20–500 Hz) and full-wave, rectified to the EMG amplitude of each jump per unit of time. Data were normalized using the EMG amplitude (%MVC) measured for each muscle during the time in which the muscle exerted MVC.

Data were presented as means (standard deviation). Paired Student's t-tests were used to assess statistical differences in EMG muscle activity (expressed as %MVC). P-values of <0.05 were considered statistically significant. To evaluate the magnitude of differences beyond statistical significance, Cohen's d effect sizes were calculated and interpreted as follows: small (0.20–0.49), medium (0.50–0.79), and large (≥0.80) (Cohen, 1992). Relative reliability was assessed using 95% confidence intervals.

RESULTS

Table 1 and Figure 2 show the results of each muscle activity during the descent and ascent phases. RF, TA, and LG muscular activities were significantly
greater in the descent phase than in the ascent phase, with a large effect size. SCM, TR, and BF muscular activities were significantly greater in the descent phase than in the ascent phase, with a medium effect size. ES muscular activity was significantly greater in the descent phase than in the ascent phase but with a small effect size. RA muscular activity was not significantly different between the two phases, with a small effect size.

Table 1
*Differences between the descent and ascent phases during EMGs amplitude (%MVC) of jumping motion on the bed.*

<table>
<thead>
<tr>
<th></th>
<th>Descent phase</th>
<th>Ascent phase</th>
<th>95%CI</th>
<th>p value</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCM</td>
<td>27.96 (20.47)</td>
<td>14.84 (15.50)</td>
<td>[0.42, 1.02]</td>
<td>&lt; .01</td>
<td>0.72</td>
</tr>
<tr>
<td>TR</td>
<td>5.16 (4.35)</td>
<td>2.14 (5.13)</td>
<td>[0.34, 0.94]</td>
<td>&lt; .01</td>
<td>0.64</td>
</tr>
<tr>
<td>RA</td>
<td>1.71 (3.22)</td>
<td>1.19 (1.65)</td>
<td>[-0.09, 0.49]</td>
<td>.18</td>
<td>0.20</td>
</tr>
<tr>
<td>ES</td>
<td>8.44 (6.05)</td>
<td>5.80 (7.73)</td>
<td>[0.09, 0.68]</td>
<td>.01</td>
<td>0.38</td>
</tr>
<tr>
<td>RF</td>
<td>8.92 (6.74)</td>
<td>4.66 (3.23)</td>
<td>[0.50, 1.11]</td>
<td>&lt; .01</td>
<td>0.81</td>
</tr>
<tr>
<td>BF</td>
<td>21.06 (38.55)</td>
<td>6.46 (9.13)</td>
<td>[0.22, 0.82]</td>
<td>&lt; .01</td>
<td>0.52</td>
</tr>
<tr>
<td>TA</td>
<td>13.33 (7.14)</td>
<td>6.99 (3.30)</td>
<td>[0.83, 1.46]</td>
<td>&lt; .01</td>
<td>1.14</td>
</tr>
<tr>
<td>LG</td>
<td>17.56 (12.47)</td>
<td>7.34 (4.33)</td>
<td>[0.78, 1.41]</td>
<td>&lt; .01</td>
<td>1.10</td>
</tr>
</tbody>
</table>

*Figure 2. Effect sizes and 95% confidence intervals for both phases in EMG amplitude.*

**DISCUSSION**

This study compared the muscle activity of the takeoff motion during the descent and ascent phases of a jump on the trampoline bed. The results showed that the activity of the LG, TA, RF, and BF muscles were all higher in the descent phase compared to the ascent phase. The greater TA activity during descent can be attributed to its role in ankle dorsiflexion before landing, as reported in previous studies (Matsushima et al., 2017; Matsushima et al., 2018; Song et al., 2011). This dorsiflexion helps in generating quick muscular strength during the short (approximately 0.15
seconds) descent phase. In essence, the plantar foot actively prepares for dorsiflexion even before landing to securely grip and push down on the bed. While TA contracts concentrically during dorsiflexion, the higher LG activity in the descent phase suggests an eccentric contraction (Matsushima et al., 2018a). This is consistent with the observed increase in ankle dorsiflexion angle from landing to maximum depth, followed by plantar flexion during ascent (Matsushima et al., 2018c). As an antagonist to TA, the eccentrically contracting LG helps control the rapid dorsiflexion in the descent phase, contributing to greater activity compared to the ascent phase. Several studies have reported a correlation between plantar pressure and jumping motion (Matsushima et al., 2018b, 2018c; Song et al., 2013). In this study, heel pressure likely peaked at maximum depth due to the dorsiflexion-induced downward push on the bed (Matsushima et al., 2018b, 2018c; SONG et al., 2013). RF and BF muscular activities pushed the bed down through hip and knee joint extension. Matsushima et al. (2017) found that the emphasis is different depending on the skill level and hip extension, jumpers prioritize either RF for knee extension or BF for hip extension. Furthermore, the angular change of the lower extremity joint was greater in the descent phase and smaller in the ascent phase. Lower extremity muscular activity contributes to the long deflection of the bed in the descent phase. Ueyama et al. (2007) emphasized the importance of pointing the body straight up vertically at the maximum depth to achieve a stable bounce. The extension of hip and knee joints during the descent phase pushes the bed down, and the vertical posture is then straightened at the maximum depth from landing. During the ascent phase, the subject bounces up, receiving the restoring force of the bed. Consequently, the extension motions in the lower extremities are performed less during the ascent phase than during the descent phase. SCM muscular activity is crucial for controlling the head and maintaining a straight vertical posture, while SCM and TR muscular activities likely contribute to head control for maintaining that posture. Given that the head has the highest mass ratio after the torso and thighs in the body (Hai−peng et al., 1994; Michiyoshi et al., 1992), controlling the head becomes significant. The RA and ES muscles, as trunk muscles, showed no significant differences in activity between the two phases, stabilizing the trunk during the jumping motion. The muscles serve distinct functions in both phases, as discussed earlier. The muscular activity that facilitates pushing down the bed for an extended duration in the descent phase is particularly crucial. Additionally, the muscles must maintain a straight posture in the ascent phase to receive the restorative force of the bed on the body and enable upward propulsion.

The load on the trampoline bed gradually increases during the sinking phase because of its elastic nature, reaching its peak when the bed starts rising from its maximum depth in the ascent phase. In the descent phase, the trampoline gymnast gradually increases the load by pushing the bed downward through lower extremity extension while falling from the air. The extension movement initiates from the maximum depth, and in the ascent phase, the trampoline gymnast jumps upward, creating a Closed Kinetic Chain (CKC) (Matsushima, 2023). An Open Kinetic Chain (OKC) is characterized by the mobility of the distal part of the body not being immobilized, while CKC involves external forces.
restricting the distal part's mobility (Steindler, 1977). Muscular activity in OKC and CKC exhibits contradictory characteristics. In OKC, the origin of the muscle is fixed, and muscle contraction moves toward the stop, whereas in CKC, the distal portion is fixed, and the muscle can move at the origin. Studies examining the relationship between lower extremity muscle strength and vertical jump in OKC and CKC revealed that lower extremity muscle strength in CKC was more strongly related to vertical jump than in OKC (Jonathan and Matthew, 1998). RF muscular activity, due to the knee joint extension movement, is significantly greater in OKC than in CKC (Escamilla et al., 1998; Spaian, 2012; Stensdotter et al., 2003). The distinct characteristics of OKC and CKC suggest the need for different training for each phase in the trampoline jumping motion. For instance, a squat exercise with the feet on the floor is CKC, while an exercise using a leg press machine (a machine with a fixed seat and a movable foot press plate) is OKC. Despite involving the same knee joint and hip joint extension movements, these exercises train different aspects due to the kinetic chain difference.

LIMITATION

A limitation of this study is that it was not possible to attach compact tension/compression load cells to many springs. If attached to too many springs, the elasticity of the spring will be lost. The next challenge will be to attach compact tension/compression load cells to many springs to accurately measure the tension of the springs so that their elasticity is not compromised. Alternatively, other methods may need to be explored for measuring tension in the springs. While this study measured the activity of eight muscles, a future challenge lies in measuring the activity of even more detailed muscles.

CONCLUSIONS

The jump is executed by maximizing the bed's restoring force. The muscular activities of RF, BF, TA, and LG were significantly higher in the descent phase than in the ascent phase to deepen the bed deflection. SCM and TR muscles were active for straight postural control at the maximum depth. Additionally, RA and ES muscles remained active from landing to takeoff for trunk stability. The elements required for the jumping motion differ between the descent and ascent phases of the bed due to the elastic nature of the bed and the distinct kinetic chain. The descent phase represents OKC as it involves landing from the air and gradually increasing the load, while the ascent phase is CKC as the load peaks when the bed rises from its maximum depth. Athletic training needs to be tailored to each phase of the jumping motion.

REFERENCES

Escamilla RF, Fleisig GS, Zheng N, Barrentine SW, Wilk KE, and Andrews JR.


Martin Kraft. (2001). A simple approach for the vertical force of the trampoline bed. The online publication system of the Technical University. https://doi.org/10.24355/dbbs.084-200511080100-65


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