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Original Article

Anticipatory Effect on Lower Extremity Muscle Recruitment and Activation Patterns During Single Leg Drop Tasks

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Abstract

Objectives: To examine the anticipatory effect on lower extremity muscle activation during single leg drop landing and jumping. **Methods**: Seventeen healthy males performed single leg drop landing and jumping, under conditions manipulating the subsequent movement after landing. Participants performed the anticipated condition (subsequent movement—land/jump—was preplanned), followed by the unanticipated condition (subsequent movement was given via visual signals). Electromyography of the gluteus medius (GM), rectus femoris (RF), vastus medialis (VM), semitendinosus (ST), biceps femoris (BF), tibialis anterior (TA), and medial gastrocnemius (MG) were obtained. The time of onset, time-to-peak amplitude (from onset or initial contact), and peak amplitude were compared ($p<0.05$). **Results**: Overall, under the unanticipated condition, the time (0 = initial contact) of onset of RF (−101 ms vs. −245 ms), TA (−116 ms vs. −232 ms) and MG (−122 ms vs. −180 ms) and time-to-peak amplitude (from initial contact) of RF (223 ms vs. 13 ms), ST (111 ms vs. −9 ms), and MG (79 ms vs. −41 ms for unanticipated and anticipated, respectively) were delayed compared to anticipated condition. **Conclusions**: When visual cues were unanticipated, participants demonstrated delayed and redistributed muscle activation timing during single leg landing and jumping.

Keywords: Electromyography, Preplanned, Onset, Peak Amplitude, Open Skill

Introduction

A single leg landing is a common athletic movement. During the landing phase (e.g., from initial contact to peak knee flexion)[1], the body weight is exerted on the lower extremity several times[2]. Although impact is absorbed and transferred through the lower extremity, excessive mechanical impact may lead to musculoskeletal injuries[3]. In the athletic environment, single leg landing is not the end of the movement; subsequent actions, such as jumping again, are also frequent. Landing and jumping movements in open-skilled sports (e.g., basketball and volleyball) are often executed under an "unanticipated" situation. This series of movements requires quick changes in neuromuscular activation in the lower extremity, which may impose an additional burden on such risky movements.

Previously, movements performed under unanticipated conditions have shown increased gluteus maximus activation during single leg landing[4] and decreased quadriceps and gastrocnemius activation during cutting task[5], compared with movements performed under anticipated conditions. These neuromuscular alterations result from adjustments in response to spontaneous visual feedback[4]. Muscle activation delay is a factor to joint injury[6,7] as it impedes dynamic stabilisation[8]. Existing data on unanticipated landing showed a longer time to activate the peroneus longus[9] as well as brevis[10], and a decreased activation of the quadriceps, hamstrings,

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and gastrocnemius[11], and tibialis anterior[10], relative to the anticipated (e.g., task after landing was preplanned) condition. Proper muscle activation timing is essential for appropriate stiffness and dynamic stabilisation of the lower extremity joints[12]. Although defining the exact "timing" of muscle activation is difficult, the onset time and time-to-peak amplitude of lower extremity muscles recorded by surface electromyography have been used[9,13,14] to identify neuromuscular alterations.

However, existing data on the timing of lower extremity muscle activation during unanticipated landings[9,11,13] have limitations. First, unanticipated tasks were performed with the participants blinded, which is unrealistic in real-athletic scenarios. Second, although data on the quadriceps[11], hamstrings[11], peroneus[10], tibialis[10,11], and gastrocnemius[11] are available, the interrelationships among these lower extremity muscles remain unknown. Lastly, neuromuscular activation in the lower extremity during an immediate jump following single leg landing under an unanticipated condition has never been examined. Developing an experimental apparatus designed to manipulate the anticipatory effect during a single leg drop landing and jumping would address the aforementioned limitations and provide a comprehensive understanding of the neuromuscular recruitment and activation patterns in the lower extremity.

Hence, the purpose of our study was to compare the time of onset, time-to-peak amplitude (from onset or initial contact to peak amplitude), and peak amplitude recorded by surface electromyography of the gluteus medius (GM), rectus femoris (RF), vastus medialis (VM), semitendinosus (ST), biceps femoris (BF), tibialis anterior (TA), and medial gastrocnemius (MG) during anticipated and unanticipated single leg landing or jumping. Based on previous data[9-11], we expected to see a delayed time of onset, longer time-to-peak amplitude, and lower peak amplitude during unanticipated landing and jumping when compared with anticipated landing and jumping.

Materials and Methods

Participants

Seventeen healthy young recreationally active (e.g., exercising at a moderate intensity of 150 min/week) males (24 ± 3 years, 173 ± 6 cm, 72 ± 9 kg) were studied. Participants had to be free of lower extremity injuries within six months and lower extremity surgery in their lifetimes. Individuals who had hypertension, cardiovascular disease, or neuromuscular disorder were excluded. Based on a previous study[10], we estimated that a minimum of 15 participants would be required to detect a difference in muscle onset timing (mean difference: 10.03 ms; standard deviation: 15.37 ms; α=0.05; β=0.20; effect size: 0.80). Because sex-related differences in lower extremity biomechanics[15] during single leg drop landing have been reported, we recruited only male participants to reduce sex-related confounding factors during single leg drop landing and jumping tasks. All participants read the testing procedures and gave informed consent, approved by the University's Institutional Review Board.

Measures

Participants were instrumented with the 14 EMG transmission probes (sensor Model 580-16M, Noraxon Inc., Scottsdale, USA), with seven probes per leg, using bipolar EMG electrodes (Product #272, Noraxon Inc., Scottsdale, USA) placed over the muscle bellies of the GM, RF, VM, ST, BF, TA, and MG on both legs. Electrodes were positioned with an inter-electrode distance of 20 mm (center-to-center), following the recommended surface EMG sensor placement procedures[16]. In minimising signal noise, the skin was prepared by shaving (if necessary) and cleaning with sandpaper and an alcohol swab. Following the EMG sensor placement, 29 reflective markers were affixed for joint kinematic analysis. Raw EMG signals were amplified with a gain of 200 and sampled at 1,500 Hz (a common mode rejection ratio of > 100 dB; bandwidth of 10–500 Hz). The EMG data with joint kinematics (sampled at 200 Hz) and vertical ground reaction force (sampled at 2,000 Hz; > 10 N) were collected under a synchronised data collection system (Qualisys Track Manager, Qualisys, Gothenburg, Sweden) during the tasks. Joint kinematics and vertical ground reaction force data were not reported in this study, but they were used to distinguish important movement events (e.g., foot off from the drop box, initial contact, peak knee flexion, and jump off).

Design and Procedures

Upon arrival at the laboratory, participants read the testing procedures and gave informed consent. After EMG electrode and reflective marker attachments, the single leg drop landing and jumping tasks were introduced. For the ready position (Figure 1), participants spread their arms and stood on their dominant foot (i.e., the foot to kick a ball) on a 40-cm-high wooden box, while their non-dominant knee and hip were flexed at 90°. Participants wore their own comfortable athletic footwear typically used for sports activities, provided that the shoes did not have excessive cushioning or an unusually high heel height. For the single leg drop landing task, participants dropped off from the box and landed onto a floor-embedded force platform (Kistler 9287BA, Kistler Instruments, Winterthur, Switzerland) with their dominant foot (Figure 1). For the single leg drop jumping task, participants performed the same landing task followed by an immediate vertical jump as high as they could and landed again on the force platform. A successful trial was defined as completing the task without any additional movements, such as hopping after landing, flexing their elbows, touching the ground with their non-dominant leg, or landing outside the force platform[17].

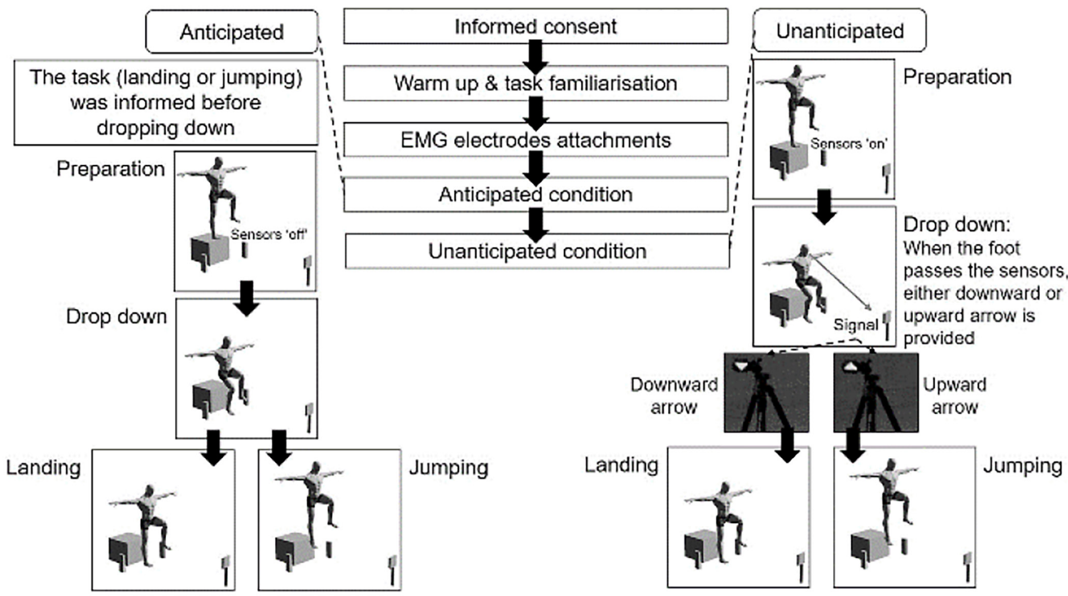

Figure 1. Study design and testing procedures.

Participants performed the single leg drop landing and jumping tasks under both anticipated and unanticipated conditions. Within the condition, the single leg drop landing and single leg drop jumping tasks were performed in a random order. In the anticipated condition, participants were informed whether they needed to perform a landing or jumping task before dropping down (at the ready position: Figure 1). In the unanticipated condition, the specific task (e.g., landing or jumping) was given during the time between dropping off from the drop box and the initial contact on the force platform via visual signals on a light-emitting diode screen located 3.6 m away from the box. When the participant's foot passed through the sensors prior to the initial contact, a downward or upward arrow icon (down for landing and up for jumping) was randomly shown on the monitor screen. Given that the arrows appeared in a random order, the unanticipated condition was conducted until three successful trials of each task were performed. Therefore, the order of conditions was fixed (anticipated first, followed by unanticipated condition) because the unanticipated condition often required additional attempts, which could induce task familiarisation and/or fatigue-related changes that might carry over to subsequent performance. For the single leg drop landing, the number of trials ranged from 3 to 9, and for the single leg drop jump, from 3 to 10. To minimise fatigue (which was not otherwise monitored), a minimum rest interval of 90 sec was provided between trials, and this was increased to at least 120 sec when participants performed more than five trials. The first three successful trials were averaged, and data from the dominant limb were analysed.

Data Processing

The collected EMG data were cropped in accordance with the following time periods: (1) single leg drop landing (from the data point where the participant's foot dropped off from the box to peak knee flexion after the initial contact) and (2) single leg drop jumping (from the same data point as the landing task to the participant's foot jumped off from the force platform). The cropped EMG data were first filtered using a 4th order zero-phase-shift Butterworth high-pass filter (cutoff frequency: 15 Hz). Afterwards, the filtered data were full-wave rectified and smoothed using a 4th order zero-phase-shift Butterworth low-pass filter (cutoff frequency: 20 Hz).

The time of onset, time-to-peak amplitude (from onset or initial contact to peak amplitude), and peak amplitude were identified within the specified time periods. The point that exceeds 8 % of the peak amplitude was defined as the onset of muscle[18], whereas the peak amplitude was defined as the highest value of the EMG data within the time periods. EMG peak amplitudes were analysed in raw microvolts and were not normalised[19]. Because all conditions were recorded within a single session with electrodes maintained in place for each participant, amplitude comparisons were limited to within-subject and within-session contrasts between conditions. Given the inherent variability of EMG signals, all algorithmically detected onset and peak events

Table 1. Peak amplitude during single leg landing and jumping under anticipated and unanticipated conditions.

	Landing			Jumping		
	Anticipated	Unanticipated	*p*-value	Anticipated	Unanticipated	*p*-value
Gluteus medius	131.9 (112.3 – 151.5)	194.6 (140.8 – 248.4)	p=0.17	374.4 (306.0 – 442.8)	344.6 (281.2 – 408.0)	p=0.46
Rectus femoris	291.3 (227.8 – 354.8)	310.1 (262.4 – 357.8)	p=0.69	586.1 (513.0 – 659.2)	597.3 (523.4 – 671.2)	p=0.72
Vastus medialis	390.3 (314.5 – 466.1)	536.9 (447.1 – 626.7)	p=0.17	927.4 (808.7 – 1046.1)	1044.5 (900.5 – 1188.5)	p=0.33
Semitendinosus	242.8 (193.3 – 292.3)	288.2 (236.5 – 339.9)	p=0.69	548.2 (465.9 – 630.5)	570.3 (460.2 – 680.4)	p=0.73
Biceps femoris	257.0 (198.7 – 315.3)	275.7 (219.0 – 332.4)	p=0.96	615.8 (515.0 – 716.6)	569.8 (465.9 – 673.7)	p=0.73
Tibialis anterior	325.9 (292.9 – 358.9)	365.5 (316.0 – 415.0)	p=0.45	541.8 (460.5 – 623.1)	664.4 (547.7 – 781.1)	p=0.11
Medial gastrocnemius	643.0 (478.4 – 807.6)	772.3 (557.2 – 987.4)	p=0.96	1632.8 (1196.2 – 2069.4)	1424.8 (1023.7 – 1825.9)	p=0.72

Note. Values are mean (95% CIs). The values were averaged across trials. All reported p-values in Table 1 are Benjamini-Hochberg adjusted. The unit is μV.

were then visually inspected by a single blinded assessor (J.L.) to confirm that the identified points represented true physiological onset and peak activity rather than transient artifacts. The assessor was blinded to the anticipatory and task condition, as the EMG files were prepared and provided in a randomised order by a separate researcher (H.D.). During this visual verification of all data, we sometimes observed brief or isolated threshold crossings prior to landing that were not accompanied by a sustained rise in the EMG envelope; these were considered spurious detections rather than meaningful muscle activation. The actual onset was determined as the time point proximal to initial contact where the signal showed a clear and sustained increase (e.g., a consistent upward trend/linear rise), which remained above the threshold for at least 25-ms (38 samples)[20].

Statistical Analysis

The normality of each outcome variable under each condition was tested using the Shapiro-Wilk test. For data that were normally distributed, paired t-tests were conducted. When the data were not normally distributed, Wilcoxon signed-rank tests were conducted. Dependent measurements were statistically compared between the two conditions within the same task (e.g., anticipated landing vs. unanticipated landing: Figure 1). Descriptive statistics were presented as means with 95% confidence intervals (CIs) for all variables. As a manipulation check (non-primary outcome), the time from signal to initial contact interval was compared between the landing and jumping using paired t-test, and the values are reported as the mean with 95% CIs. For multiple-testing correction, all p-values were adjusted using the Benjamini-Hochberg procedure separately for each task and outcome to limit the false discovery rate[21]. Within each analysis set, the seven muscle-specific comparisons between the anticipated and unanticipated conditions were treated as a single correction family. We defined the correction family in this way because the same condition contrast was tested repeatedly across the seven muscles within a given outcome, whereas the four outcomes represented conceptually distinct neuromuscular variables and were therefore not pooled into a single family. Statistical package R (version 4.1.0, R development core team) was used for all statistical analyses (p<0.05). For statistically significant findings, effect size (ES) was calculated to quantify practical significance, using Cohen's d_z for the paired t-test and the matched-pairs rank-biserial correlation for the Wilcoxon signed-rank test.

Results

The time from signal to initial contact did not differ between tasks (t=1.40; p=0.18); the mean value was 46 ms (95% CIs: 40 to 51 ms) for landing and 49 ms (95% CIs: 44 to 55 ms) for jumping.

Negative values (in ms) indicate the timing of pre-contact (0 = initial contact) muscle activity (onset or peak amplitude), while positive values indicate the timing of the post-contact muscle activity.

All reported p-values for time of onset, time-to-peak amplitude, and peak amplitude in the Results section and Table 1 are Benjamini-Hochberg adjusted.

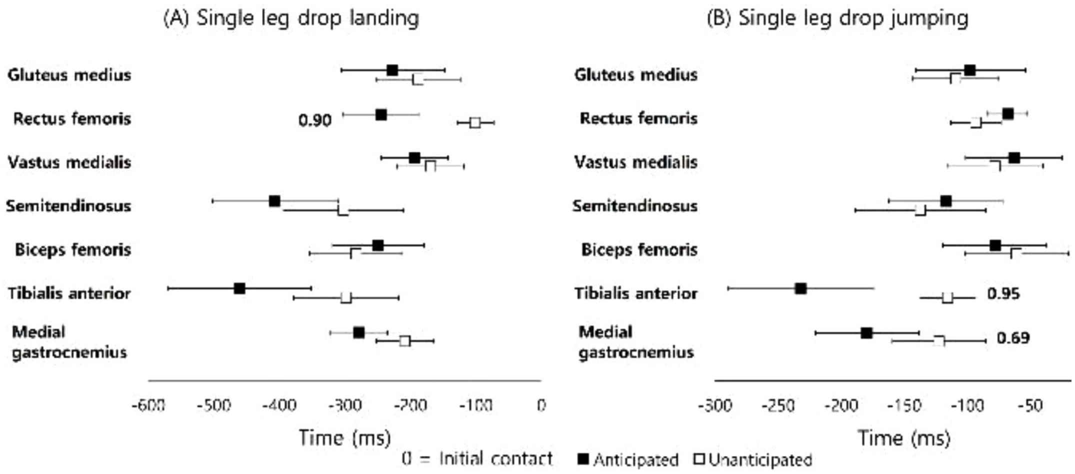

Figure 2. Time of onset in the single leg drop landing (A) and jumping (B) task between the anticipated and unanticipated conditions. Values are means and the 95% CIs. The numbers represent the effect sizes of the statistically significant differences. Initial contact was defined as time zero (0 ms); negative values indicate pre-contact onset and positive values indicate post-contact onset.

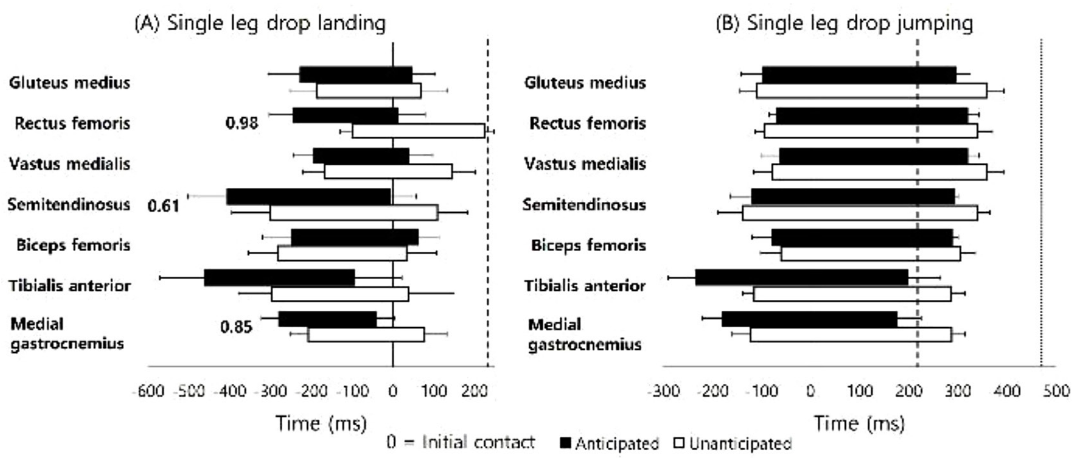

Figure 3. Time-to-peak amplitude in the single leg drop landing (A) and jumping (B) task between the anticipated and unanticipated conditions. Values are mean and the 95% CIs. The dashed lines (A and B) indicate the timing of peak knee flexion, while the dotted line (B) denotes the timing of jump-off. The numbers represent the effect sizes of the statistically significant differences. Initial contact was defined as time zero (0 ms); negative values indicate pre-contact peak activation and positive values indicate post-contact peak activation.

Time of Onset

When performing single leg drop landing, the onset of the RF (−101 vs. −245 ms, W=8, p<0.01, ES=0.90) in the unanticipated condition was delayed compared with that in the anticipated condition (Figure 2A).

When performing single leg drop jumping, the onset of the TA (−116 ms vs. −232 ms, W=4, p<0.01, ES=0.95) and MG (−122 ms vs. −180 ms, t=−2.85, p=0.04, ES=0.69) in the unanticipated condition was delayed compared with that in the anticipated condition (Figure 2B).

The time of onset in the GM (landing: W=65, p=0.57; jumping: W=81, p=0.83), RF (jumping: W=111, p=0.06), VM (landing: W=59, p=0.46; jumping: t=0.75, p=0.81), ST (landing: t=−1.44, *p*=0.29; jumping: W=82, *p*=0.79), BF (landing: t=0.85, *p*=0.48; jumping: t=−0.48, *p*=0.83), TA (landing: W=25, *p*=0.05), and MG (landing: t=−1.96, *p*=0.16) did not differ between the two conditions (Figures 2A & B).

Time-to-Peak Amplitude

From Onset to Peak Amplitude

The time from onset to peak amplitude in the GM (landing: t=0.37, *p*=0.83; jumping: t=−0.91, *p*=0.38), RF (landing: W=37, *p*=0.14; jumping: t=−1.82, *p*=0.17), VM (landing: t=−2.28, *p*=0.13; jumping: W=33, *p*=0.14), ST (landing: t=−0.09, *p*=0.93; jumping: W=38, *p*=0.17), BF (landing: W=49, *p*=0.34; jumping: t=−0.30, *p*=0.77), TA (landing: W=88, *p*=0.82; jumping: W=127, *p*=0.12), and MG (landing: t=−3.04, *p*=0.06; jumping: t=−1.65, *p*=0.17) did not differ between the two conditions (Figures 3A & B).

From the Initial Contact to Peak Amplitude

When analysing peak amplitude with reference to the initial contact, rather than the time of onset, the time to reach the peak amplitude in each muscle was observed before and after the initial contact (ranging between −96 ms and 359 ms relative to the initial contact).

When performing single leg drop landing, participants in the unanticipated condition took longer to reach the peak amplitude from the initial contact in the RF (223 ms vs. 13 ms, W=1, *p*<0.01, ES=0.98), ST (111 ms vs. −9 ms, W=30, *p*=0.04, ES=0.61), and MG (79 ms vs. −41 ms, W=11, *p*=0.01, ES=0.85) compared with those in the anticipated condition (Figure 3A).

The time from initial contact to peak amplitude in the GM (landing: W=60, *p*=0.51; jumping: t=−1.95, *p*=0.11), the RF (jumping: W=61, *p*=0.72), the VM (landing: W=21, *p*=0.06; jumping: W=39, *p*=0.11), ST (jumping: W=26, *p*=0.06), BF (landing: W=88, *p*=0.57; jumping: W=66, *p*=0.72), TA (landing: W=49, *p*=0.27; jumping: W=34, *p*=0.10), and MG (jumping: W=59, *p*=0.06) did not differ between the two conditions (Figures 3A & B).

Peak Amplitude

When performing single leg drop landing, the peak amplitude in the GM (W=35, *p*=0.17), RF (W=62, *p*=0.70), VM (t=−2.33, *p*=0.17), ST (W=60, *p*=0.69), BF (W=69, *p*=0.96), TA (W=49, *p*=0.45), and MG (W=71, *p*=0.96) did not differ between the two conditions (Table 1).

When performing single leg drop jumping, the peak amplitude in the GM (W=93, *p*=0.46), RF (W=86, *p*=0.72), VM (t=−1.78, *p*=0.33), ST (W=84, *p*=0.72), the BF (W=87, *p*=0.72), TA (W=21, *p*=0.11), and MG (W=90, *p*=0.72) did not differ between the two conditions (Table 1).

Discussion

This study aimed to examine the anticipatory effects on muscle recruitment and activation patterns in the lower extremity during single leg drop landing and jumping. Our hypotheses were partially supported, with muscle- and task-specific effects rather than uniform changes across all outcomes. The hypotheses regarding longer time from onset to peak amplitude and lower peak amplitude in the unanticipated condition compared with the anticipated condition were not supported. In particular, (1) onset timing was delayed in selected muscles (RF during landing; TA and MG during jumping); (2) the RF, ST, and MG took a longer time to reach the peak amplitude after initial contact during landing in the unanticipated condition compared with the anticipated condition; and (3) the time from onset to peak amplitude and the magnitude of peak amplitude did not differ between conditions across muscles. Our data suggest a selective reorganisation of neuromuscular activation timing under the unanticipated condition, which may reflect time-constrained influences. These altered neuromuscular activation patterns could provide practical insights into condition-specific neuromuscular control and targeted training strategies.

Characteristics of Muscle Onset by Anticipatory Condition

The onset time, which is defined as 8 %18 of the peak amplitude for each muscle, was observed before the initial contact in both conditions (e.g., anticipated and unanticipated) and tasks (e.g., landing or jumping). The onset time ranged from −63 to −407 ms for the thigh muscles and from −116 to −460 ms for the calf muscles (Figures 2A & B). Previous studies have also reported this pre-activation pattern in the thigh, ranging from −76 to −150 ms[13] and in the calf, ranging from −120 to −210 ms[14] during landing. Small differences in onset times were observed between the previous and our data. These differences could be attributed to the definition of onset, which is visual inspection by the expert[13] or 8 % of peak amplitude (our study), or different drop heights used, including 20 cm[13], 32 cm[14], or 40 cm (our study). In summary, the anticipatory mechanism[4], at least partially, accounted for the execution of landing tasks performed under anticipated and unanticipated conditions.

Implications of Delayed Muscle Onset

The onset of the RF showed a delay of 98 ms during the unanticipated landing task. Similarly, during the unanticipated jumping task, the onset of the TA and MG exhibited a delay of 117 and 57 ms, respectively. Although delayed muscle onset was observed in the unanticipated condition, pre-contact muscle activation still occurred (Figure 2). This early activation may be attributed to pre-contact neuromuscular preparation before ground contact[22]. However, a delay in pre-contact muscle activation may reflect a temporal alteration in this preparatory activation pattern. TA and MG are the dynamic stabilisers of the ankle complex in the sagittal and frontal planes[23]. The activation of the TA is essential for ankle dorsiflexion, which is known as the close-packed ankle joint position that makes the talocrural joint more congruent and supports the medial longitudinal arch, thereby preventing excessive foot pronation and maintaining ankle dynamic stability[23] during landing. The activation of the MG generates plantar flexion torque, which contributes to ankle stability and shock absorption[24]. Moreover, the MG assists in controlling the medial-lateral stability by providing inversion torque[24]. Given these functional roles, delayed onset may be associated with an alteration of neuromuscular preparation for ankle-joint control prior to ground contact under unanticipated conditions.

Characteristics of Time-to-Peak Amplitude by the Anticipatory Effect

There was a longer time from initial contact to peak amplitude in the RF, ST, and MG during the unanticipated landing, which is relative to the anticipated landing. Notably, the activation of the RF was remarkably delayed compared with the anticipated condition (unanticipated: 223 ms vs. anticipated: 13 ms, ES=0.98). Given that the RF is a biarticular muscle that controls the hip and knee joint, a delay in the activation of the RF may indicate that its contribution to coordinated hip-knee support was shifted to a later phase of landing[25]. However, the time-to-peak amplitude (from initial contact) of the lower extremity muscles did not differ between tasks, although there were trends toward longer times for the ST (p=0.06, ES=0.67) and MG (p=0.06, ES=0.74) during unanticipated jumping. This result may indicate a task-dependent neuromuscular control strategy, whereby an unanticipated condition may have a greater influence on neuromuscular activation pattern during landing—when rapid stabilisation and impact attenuation are required—than during the propulsive phase of jumping.

Implications of Delayed Time-to-Peak Amplitude

In our data, shifts in time-to-peak amplitude during landing were most evident in the RF, ST, and MG, suggesting that timing modulation under unanticipated demands may be muscle-specific rather than uniform across the lower limb. Reduced preparation time under unanticipated conditions may increase reliance on reactive control during the landing deceleration phase[26]. Given that the RF, ST, and MG are biarticular muscles spanning adjacent joints and contributing to inter-joint coordination and energy transfer[27], their activation timing may be particularly sensitive when rapid multi-joint stabilisation is required[28]. Notably, the RF time-to-peak amplitude occurred close to initial contact in the anticipated condition but appeared to shift later, toward the time of peak knee flexion during single leg drop landing under the unanticipated condition (Figure 3). Because peak knee flexion is commonly used to define the loading (deceleration) phase from initial contact[29], this pattern may indicate that peak RF activation occurred later within the loading phase under unanticipated conditions. This interpretation is consistent with the notion that reduced predictability can shift neuromuscular control away from fully proactive timing toward more reactive, within-loading-phase modulation. Given that time-to-peak amplitude should not be interpreted as a direct surrogate for joint loading or energy absorption in the absence of kinetic and kinematic data[30], these timing shifts are best interpreted as differences in neuromuscular strategy under unanticipated conditions rather than as direct evidence of compromised mechanical stability.

Regarding task-specific alterations, one plausible explanation for the more evident delay during landing than during jumping is the difference in when peak activation is typically expressed relative to initial contact. In our data, peak amplitude during landing occurred around initial contact in the anticipated condition (−86 to 61 ms) and within the early post-contact period in the unanticipated condition (33 to 223 ms), suggesting that peak expression during landing is concentrated within a short time window surrounding initial contact. By contrast, peak amplitude during jumping occurred substantially later after initial contact in both conditions (anticipated: 173 to 319 ms; unanticipated: 283 to 359 ms), which may allow more time for post-contact processing and feedback control before peak activation is expressed, thereby attenuating the anticipatory effect during propulsive phase.

Study Limitations

This study has some limitations. Our participants performed the anticipated condition first, followed by the unanticipated condition. Because the condition order was perfectly confounded, any between-condition differences cannot be attributed to anticipation alone and may reflect order-related effects (e.g., practice, familiarisation, or fatigue). Considering that the directions of the arrow signals for the unanticipated condition were displayed randomly, predicting the total number of trials the participants had to perform was difficult. Therefore, obtaining three successful trials for landing and jumping required many trials to complete the unanticipated condition. This fixed order with repetitive trials may have introduced systematic order effects (task familiarisation and/or accumulated fatigue) that cannot be separated from the differences attributed to the anticipated vs. unanticipated conditions. Because the single leg drop landing/jumping tasks are challenging even for recreationally active individuals, we performed the anticipated condition first to facilitate task familiarisation under a controlled setting. Although multiple attempts were sometimes required to obtain three successful trials, sufficient rest was provided between trials to minimise fatigue accumulation. Nevertheless, residual learning and/or fatigue effects cannot be fully ruled out when interpreting the differences between conditions. Accordingly, we interpret the present findings as condition-associated differences within this fixed-order protocol rather than the causal effect of anticipation. In addition, the time from the visual signal to initial contact interval was short, which limits interpretation in terms of fully anticipatory, pre-contact decision-making based on the visual cue. However, this short time frame was intentionally implemented to emulate a time-constrained unanticipated setting; therefore, our findings should be interpreted as reflecting time-limited unanticipated control rather than complete pre-contact re-planning. Lastly, the participants (i.e., young healthy males) and experimental design (e.g., processing time for unanticipated condition, single leg landing and jumping, fixed intervention order) in this study should be considered when generalising the results.

Conclusions

We observed a delayed onset of muscle activation and a longer time to reach peak amplitude in the lower extremity muscles under unanticipated conditions. These findings suggest altered neuromuscular timing when the subsequent movement (e.g., landing or jumping) is not anticipated after single leg drop landing. Coaches and athletes should be aware of time-constrained neuromuscular alterations associated with anticipatory effects when designing one-legged plyometric training drills, especially in open-skilled sports.

Ethics Approval

This study was approved by the Kyung Hee University's Institutional Review Board (protocol #: KHGIRB-19-221) and was conducted in accordance with the Declaration of Helsinki 1964 and its later amendments.

Authors' Contributions

JL: Conceptualisation, Data collection, Data analysis, Visualisation, Writing – original draft; HD: Conceptualisation, Data collection, Data analysis, Writing – review & editing; JCP: Conceptualisation, Data collection, Data analysis, Writing – review & editing; EK: Conceptualisation, Data analysis, Visualisation, Writing – review & editing; JP: Conceptualisation, Data analysis, Visualisation, Writing – review & editing, Supervision. All authors read and approved the final version of the manuscript.

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