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Neuromuscular Changes in Drop Jumps on Different Common Material Surfaces with Incremental Drop Heights

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Abstract: The purpose of this study was to compare changes in muscle pre-activation and short-latency responses in the lower limbs during drop jumps performed on different common soft and hard surfaces and at various platform heights. The study aimed to collect electromyography data from the rectus femoris, biceps femoris, tibialis anterior, gastrocnemius, and soleus of the dominant leg during drop jumps on sand, turf, polyurethane, and wood surfaces from platform heights of 30, 40, 50, and 60 cm. Muscle pre-activation refers to muscle activity 100 ms before ground contact during a drop jump, while short-latency responses refer to muscle activation occurring 30–60 ms after ground contact. These definitions were used to measure and analyze neuromuscular responses in the lower limb muscles during drop jumps using various surfaces and platform heights. Sand as a ground material and platform heights of 50 and 60 cm significantly enhanced pre-activation and activation in short-latency responses of the lower limb muscles (all $p < 0.01$). The difficulty of the drop jump task can enhance pre-activation and activation in the latency responses of lower limb muscles. It is recommended that athletes perform drop jumps on sandy surfaces or from platforms higher than 50 cm to induce muscle pre-activation of the lower limbs and to improve muscle activation levels in the latency responses after landing.

Keywords: biomechanics; electromyography; latency response; plyometric training; pre-activation; stretch reflex; stretch–shortening cycle

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1. Introduction

Plyometric training has been widely used in basketball, volleyball, handball, and other sports that require explosive jumps to make athletes stand out during competitions. Plyometric training can improve vertical jumping ability, explosive power, agility, and sports performance [1–4] as well as prevent sports injuries [5,6]. Plyometric exercises are based on the stretch–shortening cycle (SSC) and neuro-musculoskeletal adaptations. The principle is to use pre-stretching of the agonist muscles (where muscles are first passively elongated quickly) and combine it with active contraction of the muscles to generate a stronger contraction force in the agonist muscles. Its purpose is to combine strength, force, and speed to produce explosive and quick-response action patterns. Plyometric training combines fast eccentric and concentric contractions, reduces the time of the buffer phase, enhances power output, recruits more motor units to participate, effectively stores and releases elastic energy, and induces the stretch reflex to improve explosive performance [7,8].

The drop jump is a type of plyometric training in which the jumping technique involves dropping from a box and, upon landing, quickly jumping as high as possible [9]. Coaches and players are advised to adjust the height of the platform according to their training purposes and individualized jumping ability [10]. The risks of muscle soreness and injury during plyometric training are mainly due to the ground reaction force and the force generated by the rapid eccentric contraction of agonist muscles. Moreover, these risks are also related to the type of plyometric training [11]. Many specialized sports involve vertical jumps, sprints, or cuts on unstable surfaces (turf, sand, and laterite, among others), such as uneven turf on soccer, rugby, and baseball fields and the soft mats on which athletes land in gymnastics. Sports performances that occur on unstable surfaces can easily result in non-contact injuries to the lower limbs [12]. Recently, in response to the instability of these surfaces and to simulate movement on specific unstable surfaces, coaches have introduced plyometric training programs on the field (versus in the gym, where they are traditionally performed) with an unstable surface, which has been found to promote the synergistic contraction of agonist and antagonist muscles and improve joint stability, spine stability, unanticipated postural adjustment, and proprioception and neuromuscular control of the lower limbs [13,14].

Previous studies have pointed out that the activation of lower limb muscles during the braking phase of jumping or landing is affected by stretch load. During this phase, the muscles are pre-activated, followed by muscle activation during the stretch reflex, which has been shown to have a great impact on the performance of the SSC [15–18]. The stretch reflex is a neural response that occurs following the stimulation of muscle spindles, and the short-latency response is the earliest muscle response in the stretch reflex, with a reaction time of approximately 30–60 ms after ground contact [18–21]. Studies have shown that higher muscle pre-activation levels and short-latency response are associated with increased muscle stiffness in the lower limbs to resist the high impact load at the given landing height and achieve more efficient storage of elastic potential energy upon touching the ground [18].

Previous studies have explored the impact of the differences in material surfaces on sports performance and found that factors such as softness, rebound, cushioning, and power absorption all affect the performance of tasks [12,17,22]. However, none of these studies have examined common material surfaces on sports fields, which is a research gap that the current study aims to fill. The novelty of the current study is that it tests common material surfaces, including sand, turf, polyurethane (PU), and wood, on sports fields in combination with platform heights of 30, 40, 50, and 60 cm for drop jumps. This study aims to compare the changes in muscle pre-activation and short-latency responses in the lower limbs during drop jumps performed on different common soft and hard surfaces and at various platform heights. It is hypothesized that the muscle pre-activation level of the lower limb muscles before touching the ground and the activation level during the short-latency periods after touching the ground will be greater on harder materials and at higher platform heights.

2. Materials and Methods

2.1. Subjects

The subjects in this study were 15 university students from the department of physical education (age: 21.0 ± 2.8 years; height: 174.1 ± 5.5 cm; weight: 69.1 ± 9.7 kg). A prior power analysis was conducted using G*Power 3.1 software [23] to determine the required number of subjects. The expected effect size was set at 0.35 (medium to large effect size) [24], with alpha level (type 1 error) and power (type 2 error) set at 0.05 and 0.8 (80% statistical power), respectively. The analysis revealed that a sample size of 14 subjects would be sufficient for statistical significance. All subjects had experience performing the drop jump as part of a plyometric training program and met the inclusion criterion of having no lower limb neuromuscular or orthopedic injuries within six months prior to the experiment. The exclusion criteria were that they were unable to maintain a normal lifestyle with consistent nutritional intake or they were taking additional supplements or participating in any other lower limb muscle strength training during the experiment. Informed consent forms were signed by each subject prior to the experiment, and the study was reviewed and approved by the Institutional Review Board (TSMH IRB No. 19-108-B) for human clinical trials research ethics.

2.2. Procedures

The subjects warmed up for 10 min, including treadmill jogging and dynamic stretching of muscle groups before the formal experiment [25]. The subjects wore the same brand of sports shoes (Model s.y.m.B9025, LurngFurng, Inc., Taipei, Taiwan), which were prepared in advance in the laboratory to control the effect of the shoe air cushion on jumping performance. The subject's dominant leg was determined by the foot that is usually used to kick a ball with better accuracy and speed [26].

The muscle bellies of the rectus femoris, biceps femoris, tibialis anterior, gastrocnemius, and soleus of the dominant leg were shaved and wiped clean with a razor, sandpaper, and alcohol. The electromyography (EMG) sensors were positioned, pasted, and fixed on the muscle belly according to Cram et al. [27]. The subjects were asked to jump slightly to ensure that the EMG sensors on each muscle were secure and the EMG signals were stable. They were also asked to confirm that they would not feel uncomfortable when performing the movements. The position of the EMG sensor on the muscle was judged and the sensor pasted by the same researcher.

Drop jumps on four different materials were measured on four separate days. The maximum voluntary isotonic contractions (MVICs) of the lower limb muscles of the subjects' dominant leg were measured before each experiment. The MVICs of the rectus femoris and biceps femoris with knee flexion at 90°, as well as the MVICs of the tibialis anterior, gastrocnemius muscle, and soleus upon dorsiflexion and plantarflexion with the ankle joint at 90°, were measured. Each muscle contraction lasted for 3 s, and measurements were made three times, with a 90 s rest between measurements (Figure 1).

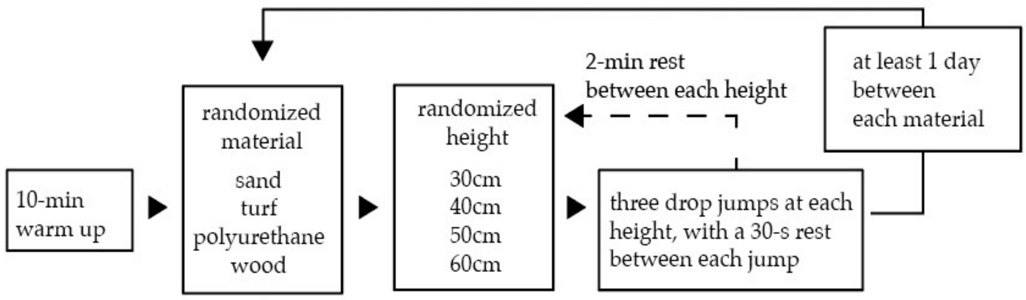

Figure 1. Experimental procedures.

To ensure proficiency in the experimental movements and to avoid sports injuries during the experiment, the subjects were required to practice drop jumping using various combinations of materials and heights at least two days before the formal experiment. Four common material surfaces found on sports fields were used in this study, namely, sand, turf, PU, and wood (Figure 2). The test orders of the material surfaces and platform heights (30, 40, 50, and 60 cm) were randomly determined by drawing lots. Many studies have shown that a height for drop jumping of between 30 and 60 cm is suitable [10,28–30]. Three drop jumps were performed at each height with a 30 s rest between each jump. The subjects rested for 2 min between each height. The tests for each material surface were performed at least 1 day apart to ensure that there was no interaction or fatigue.

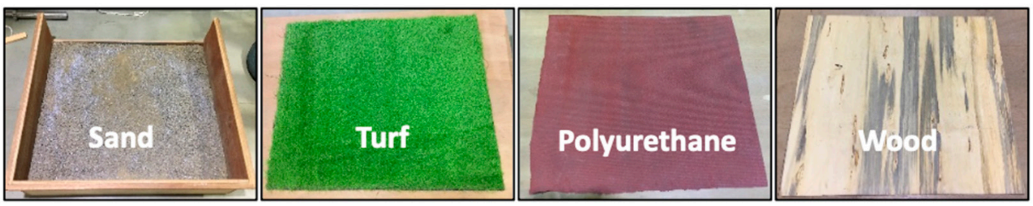

Figure 2. Four common material surfaces on sports fields.

When preparing for the drop jump, the subjects were required to place their hands next to their waist to reduce the influence of the arm swing movement, and their feet were shoulder-width apart. After hearing the start signal, the subjects were asked to lean their body and leave the platform with their dominant leg in a natural way, land on both feet, and jump off the ground quickly with their best effort.

2.3. Data Collection

An EMG system (Trigno Wireless EMG System, Delsys Inc., Boston, MA, USA) with a 2000 Hz sampling rate and two force plates (AMTI Inc., Watertown, MA, USA) with a 1000 Hz sampling rate were synchronized to collect EMG and ground reaction force data, respectively, using EvaRT software (Version 4.6, Motion Analysis Corporation, Santa Rosa, CA, USA). The force plates were 90 cm in length and 60 cm in width and placed 10 cm apart.

Customized sand, turf, PU, and wood surfaces were used in the study. The turf, PU, and wood surfaces were cut to a size of 130 cm in length and 90 cm in width to fit flat on the two force plates. Additionally, to reduce the subject's fear when landing on the sand, a larger sand area was created, measuring 130 cm in length, 108 cm in width, and with a depth of approximately 10 cm. The sand had a base (130 cm in length and 90 cm in width) that matched the size of the two force plates. When each material surface was placed on the force plate, the force plate signal was re-calibrated and reset to zero to ensure no interference due to material surface noise or weight.

2.4. Data Analysis

MotionMonitor (Innovative Sports Training, Inc., Chicago, IL, USA) software was used to analyze the EMG and ground reaction force data. A threshold of 20 N ground reaction force was used to define the instants before and after ground contact. Previous studies have shown that the muscle pre-activation begins 100 to 150 ms before ground contact in the drop jump [15–18]. Therefore, the extraction period in this study was set to 100 ms before ground contact for analysis of muscle pre-activation. The latent periods for lower limb muscle activation were set to 30–60 ms after ground contact for analysis of the short-latency responses [17,18,21]. Muscle pre-activation and short-latency responses are indicators of the neuromuscular function of the lower limb muscles.

The EMG signals of each muscle were processed by a band-pass filter at 10–500 Hz, and the root mean square (RMS) calculation was then performed. The window used for the RMS was 50 ms. The average RMSs from 0.5 to 2.5 s during the MVICs of each muscle over 3 s were taken as the reference values for normalization of the EMG. The RMS values of three drop jumps in each condition were averaged for the analysis and then normalized to the condition with the wood surface and platform height of 40 cm in each respective period of muscle activation for comparison.

2.5. Statistics

Statistical analyses were performed using SPSS version 18.0 software (SPSS Science Inc, Chicago, IL, USA). Descriptive statistics (mean $\pm$ SD) were presented for all outcome measurements. Repeated-measures 4×4 two-way ANOVA (four material surfaces $\times$ four platform heights) was used to compare the differences in material surfaces and platform heights on the EMG of the lower limb. If the interaction reached a statistically significant level, the simple main effect was analyzed further. If not, a comparative main effect analysis was performed. When the effect analysis reached significance, the Bonferroni method was used for post hoc comparison. An adjusted statistical significance level was set at $\alpha = 0.01$.

3. Results

Comparisons of normalized EMG over 100 ms before ground contact are shown in Table 1. There was no interaction between material and height for any muscle. The main effect of material was significant for the gastrocnemius, soleus, rectus femoris, and tibialis anterior. The main effect of height was significant for the gastrocnemius, soleus, biceps femoris, rectus femoris, and tibialis anterior. Further post hoc comparisons found that pre-activation of the gastrocnemius, soleus, rectus femoris, and tibialis anterior was significantly greater in sand than in turf, PU, or wood. Pre-activation of the tibialis anterior was significantly greater in sand than in turf. Pre-activation of the gastrocnemius, soleus, biceps femoris, rectus femoris, and tibialis anterior was significantly greater at 50 and 60 cm heights than at 30 and 40 cm heights. Pre-activation of the biceps femoris and rectus femoris was significantly greater at a 60 cm height than at a 50 cm height.

Table 1. Comparisons of normalized EMG 100 ms before ground contact.

Pre-Activation				
Gastrocnemius $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	1.01 ± 0.58	1.18 ± 0.57	1.48 ± 0.93	3.99 ± 4.44
40 cm ^{y,z}	1	1.36 ± 0.97	1.58 ± 1.44	3.86 ± 3.95
50 cm ^{w,x}	1.49 ± 0.54	1.59 ± 1.04	2.08 ± 1.91	4.30 ± 4.23
60 cm ^{w,x}	1.61 ± 0.98	1.73 ± 1.31	1.93 ± 1.29	4.51 ± 3.29
Soleus $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	1.07 ± 0.41	1.01 ± 0.60	1.05 ± 0.48	1.91 ± 0.97
40 cm ^{y,z}	1	1.12 ± 0.66	1.18 ± 0.51	2.23 ± 1.04
50 cm ^{w,x,z}	1.48 ± 0.50	1.44 ± 0.79	1.56 ± 0.63	2.60 ± 1.23
60 cm ^{w,x,y}	1.72 ± 0.63	1.98 ± 1.18	1.80 ± 0.85	3.25 ± 1.65
Biceps femoris $^{\#}$				
	Wood	PU	Turf	Sand
30 cm ^{y,z}	0.84 ± 0.30	1.10 ± 0.69	1.07 ± 0.52	1.64 ± 1.31
40 cm ^{y,z}	1	1.51 ± 1.46	1.23 ± 0.77	1.75 ± 1.11
50 cm ^{w,x,z}	1.81 ± 1.51	2.23 ± 1.84	1.86 ± 1.25	2.36 ± 1.88
60 cm ^{w,x,y}	2.19 ± 1.29	3.37 ± 2.81	2.41 ± 1.61	2.59 ± 1.96
Rectus femoris $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	0.76 ± 0.32	0.91 ± 0.70	1.21 ± 0.56	3.27 ± 2.74
40 cm ^{y,z}	1	1.39 ± 0.85	1.49 ± 0.93	3.73 ± 3.52
50 cm ^{w,x,z}	1.79 ± 0.77	2.24 ± 1.45	1.90 ± 1.07	4.31 ± 3.85
60 cm ^{w,x,y}	1.90 ± 0.97	3.13 ± 2.41	2.39 ± 1.35	5.03 ± 3.96
Tibialis anterior $^{@,\#}$				
	Wood ^{a}	PU ^{a,b}	Turf ^{a,c}	Sand ^{b,c,d}
30 cm ^{y,z}	0.99 ± 0.54	0.71 ± 0.40	0.88 ± 0.53	2.09 ± 1.10
40 cm ^{y,z}	1	0.84 ± 0.35	1.21 ± 0.66	2.44 ± 1.39
50 cm ^{w,x}	1.77 ± 0.78	1.25 ± 0.77	1.71 ± 0.86	3.23 ± 2.23
60 cm ^{w,x}	1.89 ± 0.65	1.69 ± 1.09	2.20 ± 1.09	3.98 ± 2.46

$^{@}$ Significant main effect between materials; $^{\#}$ Significant main effect between heights; ^{a} Significantly different from sand; ^{b} Significantly different from turf; ^{c} Significantly different from PU; ^{d} Significantly different from wood; ^{w} Significantly different from 30 cm; ^{x} Significantly different from 40 cm; ^{y} Significantly different from 50 cm; ^{z} Significantly different from 60 cm. $p < 0.01$. The RMS values were normalized to the condition with a wood surface and a 40 cm drop height, so the value in this condition was 1.

Comparisons of normalized EMG 30–60 ms after ground contact are shown in Table 2. There was no interaction between material and height for any muscle. The main effects of material and height were significant in the gastrocnemius, soleus, biceps femoris, rectus femoris, and tibialis anterior. Further post hoc comparison found that normalized EMG 30–60 ms after ground contact in the gastrocnemius, soleus, rectus femoris, and tibialis anterior was significantly greater in sand than in turf, PU, or wood. Normalized EMG 30–60 ms after ground contact for the biceps femoris was significantly greater in sand than in PU or wood. Normalized EMG 30–60 ms after ground contact for the gastrocnemius, soleus, biceps femoris, rectus femoris, and tibialis anterior at 50 and 60 cm heights was significantly greater than at 30 and 40 cm heights, while that at a 60 cm height was significantly greater than at a 50 cm height. Normalized EMG 30–60 ms after ground contact in the biceps femoris at a 40 cm height was significantly greater than at a 30 cm height.

Table 2. Comparisons of normalized EMG 30–60 ms after ground contact.

Short Latency Response				
Gastrocnemius $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	0.87 ± 0.34	0.87 ± 0.32	1.07 ± 0.40	2.26 ± 1.69
40 cm^{y,z}	1	1.10 ± 0.36	1.09 ± 0.50	2.40 ± 2.02
50 cm^{w,x,z}	1.68 ± 0.48	1.48 ± 0.48	1.65 ± 0.68	2.75 ± 1.98
60 cm^{w,x,y}	2.14 ± 0.76	1.97 ± 1.04	1.90 ± 0.74	3.19 ± 1.85
Soleus $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	0.91 ± 0.79	0.77 ± 0.36	0.91 ± 0.33	3.34 ± 3.23
40 cm ^{y,z}	1	1.38 ± 0.94	1.35 ± 0.70	3.71 ± 2.92
50 cm ^{w,x,z}	1.85 ± 0.46	2.33 ± 1.92	2.28 ± 1.60	5.13 ± 3.86
60 cm ^{w,x,y}	2.73 ± 1.75	3.82 ± 3.31	2.60 ± 1.61	6.61 ± 4.14
Biceps femoris $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf	Sand ^{c,d}
30 cm^{x,y,z}	0.93 ± 0.39	0.87 ± 0.35	1.13 ± 0.49	1.79 ± 1.44
40 cm^{w,y,z}	1	1.10 ± 0.51	1.24 ± 0.69	2.34 ± 1.94
50 cm^{w,x,z}	1.81 ± 1.57	1.85 ± 0.92	2.08 ± 1.03	3.64 ± 2.50
60 cm^{w,x,y}	2.49 ± 1.05	3.12 ± 2.31	3.07 ± 3.01	4.49 ± 2.98
Rectus femoris $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	0.79 ± 0.61	0.93 ± 0.72	1.07 ± 0.66	6.52 ± 7.38
40 cm ^{y,z}	1	1.40 ± 0.78	1.54 ± 1.10	7.39 ± 7.74
50 cm ^{w,x,z}	1.94 ± 0.95	2.67 ± 2.33	2.57 ± 2.09	10.06± 9.53
60 cm ^{w,x,y}	3.09 ± 2.51	4.64 ± 4.19	3.04 ± 2.41	12.82 ± 10.59
Tibialis anterior $^{@,\#}$				
	Wood ^{a}	PU ^{a}	Turf ^{a}	Sand ^{b,c,d}
30 cm ^{y,z}	0.81 ± 0.65	0.70 ± 0.30	0.92 ± 0.39	3.67 ± 4.37
40 cm ^{y,z}	1	1.16 ± 0.57	1.48 ± 0.90	3.48 ± 3.08
50 cm ^{w,x,z}	2.12 ± 0.63	2.29 ± 1.26	2.51 ± 1.43	4.98 ± 3.29
60 cm ^{w,x,y}	3.22 ± 1.74	4.05 ± 2.51	3.62 ± 2.46	6.91 ± 5.28

$^{@}$ Significant main effect between materials; $^{\#}$ Significant main effect between heights; ^{a} Significantly different from sand; ^{b} Significantly different from turf; ^{c} Significantly different from PU; ^{d} Significantly different from wood; ^{w} Significantly different from 30 cm; ^{x} Significantly different from 40 cm; ^{y} Significantly different from 50 cm; ^{z} Significantly different from 60 cm. $p < 0.01$. The RMS values were normalized to the condition with the wood surface and 40 cm drop height, so the value in this condition was 1.

4. Discussion

After literature searching in Scopus, Web of Science, and Pubmed, we affirm that this is the first study to investigate the effects of common material surfaces on sports fields on the muscle pre-activation and short-latency responses of the lower limb muscles. The study revealed that a sand surface induced muscle pre-activation 100 ms before ground contact and activation of the latency response 30–60 ms after ground contact in lower limb muscles more efficiently compared to turf, PU, and wood surfaces. Similarly, platform heights of 50 and 60 cm induced muscle pre-activation 100 ms before ground contact and activation of the latency response 30–60 ms after ground contact of the lower limb muscles more efficiently compared to platform heights of 30 and 40 cm. No significant differences were observed among the turf, PU, and wood surfaces.

This study's findings indicate that the use of sand as a ground material and platform heights of 50 and 60 cm significantly enhance the pre-activation of lower limb muscles. Previous literature has suggested that, during SSC, muscle pre-activation plays an important role in sports performance and the output of strength is positively correlated with muscle pre-activation [8,31,32]. Furthermore, an increase in the height of the drop jump is associated with enhanced muscle pre-activation, as well as an enhanced stretch reflex of the spinal cord [18]. The drop jump is considered one of the most important methods in the development of explosive power and is also the most intensive training [18]. The neuromuscular control system initiates feed-forward control (i.e., pre-programmed muscle activation) and subsequently triggers feedback action control (i.e., the stretch reflex) to pre-activate the muscles in anticipation of the reaction force that the joint will be subjected to and forms appropriate muscle stiffness. This also helps systematically protect the joint tissue structure and cushion the force based on specific action experiences [30,33]. The increased pre-activation of the lower limb muscles on the sand surface in the current study contradicts previous findings of reduced pre-activation of lower limb muscles (soleus, gastrocnemius, and tibialis anterior) on unstable/foam surfaces [17,18]. However, the outcome of increased pre-activation of the lower limb muscles at a platform height of 60 cm is in agreement with previous findings [18]. This may be because the sand surface is much more unstable than the foam surface, and, thus, anticipation of the difficulty of the drop jump task may have enhanced the pre-activation of lower limb muscles.

This study's findings show that the sandy surface not only enhances the pre-activation of lower limb muscles but also prolongs the effect of the short-latency response. Stretch reflex signals can be categorized into short, medium, and long-latency responses and long-latency response 2 [18–20]. Among these, the short-latency response is the earliest and is a short muscle reflex [19,21]. Generally, short-latency muscle responses in lower limb muscles do not appear during normal walking, but they appear during intense activities such as running or jumping, especially in the gastrocnemius and soleus muscles [20]. In the current study, drop jumping on sandy turf, PU, and wood surfaces is intensive enough to elicit short-latency muscle responses. A sandy surface induced a stronger pre-activation of lower limb muscles than turf, PU, or wood surfaces, and this difference continued into the short-latency response. Training can lead to neuromuscular adaptation and improved neuromuscular coordination, which can enhance muscle strength; however, the instability of the material surface can affect the acute response of the muscles and neuromuscular adaptation [12].

This study found that the impact of heights of 50 and 60 cm on lower limb muscle activation mainly continued to the short-latency response. The pre-activation period was followed by muscle activation in the latency period. The short-latency response is considered to be the earliest and is a short muscle reflex among muscle responses. Moreover, the level of muscle activation at this stage was positively correlated with action execution mode and intensity of action. Previous studies have revealed that an increase in strength or height, such as jump distance, jump height to landing, or jump difficulty, induces the muscles in the short-latency period to recruit more motor units to complete the action [18,21]. Therefore, the increase in muscle activity in the short-latency period is important for better muscle stiffness during the eccentric phase at the initial ground contact. To estimate muscle activation in the short-latency period from the pre-activation period, Lesinski et al. [18] proposed that the increase in muscle activation during the pre-activation period may trigger a subsequent stretch reflex. In particular, stretch load during the short-latency period may regulate muscle activation. The activation levels of the lower limb muscles from the pre-activation period and short-latency period may increase muscle stiffness in the lower limbs to respond to the high impact load generated by the landing height, as well as to store elastic potential energy more efficiently upon landing. Therefore, it can be inferred that the muscle activation levels during the pre-activation period and short-latency period are highly correlated. From a functional point of view, such a connection is considered to be able to fully regulate muscle stiffness [21]. Taube et al. [19] pointed out that the purpose of plyometric training was to promote SSC, while the stretch reflex can promote muscle stiffness to benefit SSC. Muscle activation during the latent period is the earliest muscle response in the SSC mechanism. Therefore, increases in muscle activity in the latent period may contribute to muscle stiffness, especially during the eccentric phase of a drop jump.

The limitations of this study include the fact that the participants were all male college athletic students, which limits the generalizability of the findings to other age groups, female individuals, or professional athletes. The small sample size of the study may limit the generalizability of our findings to other populations or contexts. Future studies with larger sample sizes may be needed. Additionally, the study used self-made simulated material surfaces in a sports biomechanics laboratory, which may have had slightly different characteristics than real sports fields. For example, the sand used in this study was a mixture of sand and small gravel, which may have affected the density and softness of the surface. Similarly, the turf used in this study was artificial turf with synthetic fibers, which may have affected cushioning and shock absorption.

It is important to note that this study focused solely on the neuromuscular aspects of the lower limb muscles, rather than on drop jump performance measures such as jump height, reactive strength index, rate of force development, peak ground reaction force, and impulse. Therefore, it is recommended that future studies should investigate whether vertical jump performance is actually improved by training in this way.

5. Conclusions

A surface of sandy ground and platform heights of 50 and 60 cm were found to efficiently induce muscle pre-activation and activation in the short-latency response of lower limb muscles. Furthermore, the difficulty level of the drop jump task was observed to enhance pre-activation and activation in the latency responses of the lower limb muscles. Based on these findings, it is recommended that athletes perform drop jumps on sandy surfaces or from platforms higher than 50 cm to induce pre-activation of the lower limb muscles and to improve muscle activation levels in the latency responses after landing.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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