

1 **Title: Synergistic dominance induced by hip extension exercise alters biomechanics**
2 **and muscular activity during sprinting and suggests a potential link to hamstring**
3 **strain**

7 **Abstract**

8 Hamstring strain is likely to occur during the late swing phase or the first half of the
9 stance phase in sprinting. During the late swing phase, the hamstrings and gluteus
10 maximus (Gmax) contract eccentrically to decelerate the lower limb. We hypothesized
11 that, when the Gmax becomes dysfunctional because of delayed onset muscle soreness
12 (DOMS), hamstring workload is increased (synergetic dominance), which could lead to
13 an increased risk of strain. A total of healthy 15 male undergraduate or graduate
14 students (age 23.1 ± 1.28 years) were recruited to perform exercises and maximal sprints.
15 On Day 1, prior to participants performing DOMS-causing exercises, and on Day 3,
16 while participants were experiencing DOMS in the Gmax, lower limb biomechanical
17 and muscle activity data were recorded using a motion analysis system and
18 electromyography (EMG), respectively. Data were analyzed and compared between
19 Day 1 and Day 3. Hip flexion angle on Day 3 was significantly lower than that on Day
20 1, but the opposite was true for knee flexion angle ($P < .05$). Vastus medialis (VM),
21 biceps femoris (BF), and Gmax muscle activities on Day 3 were significantly higher
22 than those on Day 1 ($P < .05$). Peak propulsive forces on Day 3 were significantly
23 higher than those on Day 1 ($P < .05$). Kinematic changes such as decreased hip flexion
24 angle and EMG changes such as increased BF EMG activity on Day 3 to compensate
25 for the loss of function of the Gmax may increase hamstring load and cause it to
26 become fatigued more rapidly.

28 **Key Words:** late swing phase, hamstring strain, delayed onset muscle soreness, gluteus
29 maximum, synergistic dominance

31 **Introduction**

Hamstring strain is a common musculoskeletal injury in sports, especially in those that require frequent intermittent sprinting, such as soccer (11), American football (18), and rugby (5). Hamstring strain is characterized by high recurrence (5), relatively long rehabilitation periods and associated time-loss (5), financial expenses at club- and society level (16), and impaired athletic performance (39) ; the biceps femoris (40) is affected most often. One review (12) recognized that the most common risk factors for hamstring strain included age, quadriceps peak torque, and previous hamstring strain.

Hamstring strain is likely to occur during the late swing phase (32) or the first half of the stance phase during sprinting (23). During the late swing phase, hamstring muscles and the gluteus maximus (Gmax) contract eccentrically to decelerate the lower limb (26). During that phase, the hamstring muscles reach their maximum elongation (38). In general, eccentric contraction exerts a greater force when absorbing energy than concentric contraction, which puts more strain on the muscle (21). One of the main characteristics of the hamstrings is that they are biarticular muscles, working as knee flexor agonists and as hip extensor synergists.

Another study using a 3-dimensional musculoskeletal model reported that, when maximum strength of Gmax was reduced, which resulted in increased activation of hamstrings during hip extension (22). Therefore, if the Gmax, an agonist for hip extension, cannot function normally (e.g., as a result of fatigue or muscle soreness), then the hamstrings are subjected to both knee flexion and hip extension loads—synergistic dominance (7). Synergists (in this case, hamstrings are synergist for hip extension) are usually smaller in size and have less strength than agonists, so when they must function as an agonist, they fatigue quickly and are at increased risk of being strained (7).

In an athlete's movements such as sprinting or jumping, the hips, especially the gluteus maximus, which is the most powerful muscle in the body, play a very important role. For this reason, the exercises emphasizing hip extension such as back squat and lunge, which train the gluteal region, are essential for athletes. However, considering the above-mentioned synergistic dominance, it is possible that after training with emphasis on hip extension, delayed onset muscle soreness (DOMS) and other influences may have reduced the muscle output of the gluteal muscles, especially the gluteus maximus, and unknowingly increased the load on the hamstring during athletic movements. DOMS are usually caused by eccentric movements(6),

1 especially with greater amounts of exercises, and its characteristics are decreased range
2 of motion and force, increased soreness, and creatine kinase (CK) in blood, which are
3 generally peak after about 48 hours(20, 35, 43).

4 To our knowledge, although Martinez (24)focused on synergistic dominance
5 by the hamstring and studied the muscle activity of the Gmax effected by reciprocal
6 inhibition due to hip flexor tightness during squatting, there has been no study regarding
7 how DOMS-affected Gmax effects on hamstring focusing on synergistic dominance
8 during sprinting. Therefore, in this study, we aimed to examine the effects on the
9 hamstring when the gluteal muscles such as Gmax could not function normally because
10 of DOMS during the late swing phase of sprinting. We hypothesized that when the
11 strength and efficiency of the Gmax are diminished from the effects of DOMS, kinetic,
12 kinematic, and EMG patterns will be altered (hamstring and Gmax coordination), and
13 consequently, the hamstrings will be subjected to greater loads and put it at higher risk
14 for hamstring strain.

17 **Methods**

19 **Experimental Approach to the Problem**

21 This study was a crossover study design to examine how the Gmax muscle affected by
22 delayed onset muscle soreness (DOMS) effects on hamstrings during sprinting. A total
23 of healthy 15 male undergraduate or graduate students (age 23.1 ± 1.28 years). To
24 compare the differences in lower limb kinetic, kinematics and EMGs between day 1 and
25 3, this experiment was performed for three days; on Day 1, prior to participants
26 performing DOMS-causing exercises, and on Day 3, while participants were
27 experiencing DOMS in the Gmax, lower limb biomechanical and muscle activity data
28 were recorded using a motion analysis system and electromyography (EMG),
29 respectively. The degree of DOMS was measured by maximal muscular voluntary
30 contraction and pressure pain for muscle soreness. Data were analyzed and compared
31 between Day 1 and Day 3 using Wilcoxon signed-rank tests.

33 **Subjects**

Based on data from a previous study (30) that was similar to the current study, we calculated, using software (G*power, v3.1.9.6, Heinrich Heine University Düsseldorf, Düsseldorf, Germany), that a sample of 15 participants would be required to achieve 80% statistical power with an exploratory alpha level of .05 and a large effect size of 0.8 (t-test–based calculation). Individuals who were physically active, defined as regularly performing aerobic exercises such as walking or bicycling (2), without history of lower limb pathology were recruited. This study was performed according to the Declaration of Helsinki and approved by the ethics committee of Kyoto University of Advanced Science (approval #29-5). Before participation, each person was informed of the risks and benefits of the study; each participant gave written informed consent.

Procedures

Svensson et al.(36) reported that there was no difference in hamstring injury between dominant and non-dominant legs. Also, Cross et al. (9) reported that male collegiate athletes were more likely to sustain a hamstring injury than female athletes based on National Collegiate Athletic Association athletic seasons (2004-2007). Thus, we recruited male participants (data are given as mean $\pm$ SD; age 23.1 ± 1.28 years, height 170.2 ± 4.30 cm, body weight 65.5 ± 4.95 kg) and used the dominant leg (all participants were right legged) for this experiment. We created a condition that caused DOMS in the participants based on previous studies (35, 43). Maximal muscular voluntary contraction and muscle soreness are considered to be the effective indicators to quantify the degree of DOMS, and muscle damage from DOMS is greatest 48 hours after exercise (8, 35, 43). We measured isometric contraction using a hand-held dynamometer (Anima Inc, μ Tas F-1, Tokyo, Japan), which has been shown to be reliable in previous studies(37, 42). The knee extension–flexion and hip extension measurement methods that were used have been described in detail by Eek et al.(10).Regarding muscle soreness, we used an algometer(Matsumiya Medical Seiki Manufacturing Co., FP meter, Tokyo, Japan), which is also reliable tool(interclass correlation coefficient [ICC])for intra-rater reliability=0.7)(19), to measure pressure pain for vastus medialis (VM), biceps femoris (BF), Gmax, and gluteus medius (Gmed) muscle. On Day 1, the hand-held dynamometer and algometer measurements were taken, and jogging, maximal sprints, and DOMS-causing exercises were performed. On

Day 2 (24 hours after DOMS-causing exercises), the hand-held dynamometer and algometer measurements were taken. On Day 3 (48 hours after DOMS-causing exercise and the day on which DOMS was most likely to occur), the hand-held dynamometer and algometer measurements were taken, and maximal sprints were performed. As for pressure pain, it was marked the center of each muscle belly on the first day and measure pressure pain at the same spot for three days(20). This experimental procedure is summarized in Table 1. Light gates (Brower TCi Timing System Set, Draper, UT, United States) were placed at a start line and 3 m from the start line, for calculating and confirming the running speed over the 3-m distance(17). More details are provided elsewhere by Iguchi et al. (17). Alexander (1) reported that the speed threshold between walking and running is approximately 2.5 m/s. Thus, all participants were instructed to jog at approximate speeds just above 2.5m/s. Participants wore tight-fitting clothing with bare feet. After riding a stationary bike (at self-selected speeds) for 10 minutes as a warming-up, participants practiced 3-m jogs and sprints. Participants performed approximately five jogging trials (Day 1) and 6 maximal sprinting trials (Day 1 and 3). Jogging data were used to normalize electromyography (EMG) data(3), and maximal sprinting data were used to compare Day 1 and Day 3 performances.

DOMS-Causing Exercise

DOMS is common in our daily lives and is mainly caused by eccentric contractions(6). DOMS associated decreased muscle strength or range of motion, and increased creatine kinase activity usually peak approximately 48 hours after exercise and last for several days(35, 43). In this study, it was necessary to generate DOMS in the Gmax. McCurdy et al. (25) compared hamstrings and gluteus maximus muscle activity during exercise in single-leg squats, bilateral squats, and stiff-leg dead lifts and showed that single-leg squats had the highest Gmax muscle activity. Furthermore, Jamurtas et al. (20) reported that large repeated bouts of exercise with eccentric contraction causes more serious DOMS. Thus, we used single-leg squats with multiple sets to cause DOMS in the Gmax. To perform the DOMS-causing exercise, participants held a 10 kg dumbbell in front of their chest with their dominant leg in front and their other leg behind, raised, and with the toe resting on top of the box (Figure 1). Participants were asked to perform

10 sets of 15 repetitions, and when they were unable to continue, the weight was decreased by 5 kg.

Data Collection

Heiderscheit et al. (15) reported that hamstring strain was most likely to occur during the late swing phase (from 130 ms before to when the heel touches the ground); however, they included the very initial part of the stance phase. In addition to using a 15% inclined surface, instead of muscle activity onset, they estimated the time of hamstring strain onset using the non-cyclic movement of markers attached to the upper and lower extremities, which is not a well-established method (15). Orchard (29) concluded that hamstring strain occurs during the stance phase and reported findings that ground reaction forces (GRFs) during sprinting are equal to approximately 300% of body weight, putting hamstring at higher risk of muscle strain. For these reasons, we decided to record EMG and kinematics during the second half of the swing phase just prior to (130 ms) heel contact and kinetics during the stance phase (from heel contact to toe-off).

EMG data were collected using an 8-channel telemetry system (Nrxon Telemyo Inc., model 2400 TV2, Scottsdale, AZ, United States) with a sampling rate of 1000 Hz and using 4 wireless EMG amplifiers. After skin preparation (shaving and cleaning the participant's skin with alcohol), bipolar surface electrodes (Ambu Blue Sensor, Ballerup, Denmark) and EMG amplifiers were placed according to guidelines(33) to record VM, BF, Gmax, and Gmed muscle activities. We used the EMG data from jogging (recorded on Day 1) to normalize(3) the EMG data from maximal sprinting (from both Day 1 and Day 3).

The flexion angle and angular velocity of the hip and knee during the late swing phase were recorded using a 3-dimensional motion analysis system (Vicon Industries Inc., Oxford, United Kingdom) with a sampling rate of 200 Hz, 7 high-speed cameras, and 35 retro-reflective markers (14 mm) placed on the participants (Vicon Plug-In Gait Full Body Model). Kinetic data were recorded with a multiple component force plate (Kistler Instruments Inc., model 9286A, Winterthur, Switzerland) with a sampling rate of 1000 Hz, which measured vertical ground reaction force, propulsive force (in the same direction as direction of running), and braking force (in the direction

opposite to the direction of running) during the time from initial heel contact to toe-off. We defined initial heel contact as a vertical ground reaction force exceeding the first 10 N and toe-off as vertical ground reaction force exceeding the last 10 N(14). Furthermore, we simultaneously recorded hip and knee flexion–extension moments and kinematic knee and hip data.

Data Analysis

Raw EMG signals were full-wave rectified, filtered with a Butterworth bandpass filter (30-1000Hz) (31); and root mean squared using MATLAB (R2019a; The MathWorks, Inc., Natick, MA, United States). Kinematic data (hip and knee motion) were quantified using Vicon Clinical Manager software (Oxford Metrics Ltd., United Kingdom); further details can be found elsewhere(17). External joint moments were calculated using Vicon Nexus (Oxford Metrics Ltd., United Kingdom) with standard inverse dynamics. Kinetic data were normalized by participant body weight.

Statistical Analysis

Analyses were performed using IBM SPSS Statistics for Mac (version 24.0, IBM Corp., Armonk, NY, United States). The Shapiro-Wilk test was used to verify normality. If data were not normally distributed, non-parametric statistical tests were applied. Since most were not normally distributed; sprint time; peak strength and pressure pain after DOMS; hip/knee angle, angular velocity, and moments; EMG activity; and ground reaction forces are presented as mean and standard error (SE). To compare knee flexion/extension, hip extension peak strengths and pressure pain from Day 1 through Day 3, if data were normally distributed, a repeated one-way analysis of variance (ANOVA) was applied and, if data were not normally distributed, a Friedman tests was applied. If a main effect was observed, the Scheffe test (for normally distributed data) or Bonferroni correction (for non-normally distributed data) was used to compare the 3 days. For maximum sprint times, kinetics, kinematics and ground reaction forces between Day 1 and Day 3, since these data were not normally distributed, paired sample Wilcoxon signed-rank tests were used. The effect size was calculated for the Wilcoxon signed-rank tests based on z scores, with $r < 0.3$ considered a small effect size, $0.3 \leq r <$

0.5 considered a medium effect size, and $r \geq 0.5$ considered a large effect size (33).
The level of significance was set at .05.

Results

There were significant main effects (from DOMS-causing exercise) for peak strength for knee flexion and hip extension from Day 1 to 3 ($p = .0057$ and $p = .0011$, respectively), although there was no significant main effect on peak strength for knee extension ($p = .085$) (Figure 2). Peak strengths for knee flexion on Day 2 and hip extension on Day 2 and Day 3 were significantly lower ($p = .017$, $p = .008$, and $p = .004$, respectively) than those for Day 1 (Figure 2). Peak strength for knee flexion for Day 2 was significantly lower than that for Day 3 ($p = .014$) (Figure 2). There were significant main effects for pressure pain for VM, BF, Gmax, and Gmed from Day 1 to 3 ($p = .001$, $p = .0008$, $p = .00005$, and $p = .009$, respectively) (Figure 3). Pressure pain for VM, Gmax and Gmed on Day2 and 3 were significantly lower ($p = .003$, $p = .004$, $p = .02$, $p = .02$, $p = .002$, and $p = .03$, respectively) than those for Day 1(Figure 3). Furthermore, pressure pain for BF on Day2 was significantly lower ($p = .01$) than those for Day 1(Figure 3). There was no significant difference between maximal sprint time on Day 1 and Day 3 ($p = .22$) (Figure 3). Hip flexion angle on Day 3 was significantly lower than that on Day 1 ($p = .027$) (Table 2). On the other hand, knee flexion angle on Day 3 was significantly higher than that on Day 1 ($p = .01$) (Table 2). VM, BF, and Gmax muscle activity levels on Day 3 was significantly higher than those on Day 1 ($p = .0098$, $p = .0018$, and $p = .012$, respectively) (Figure 4). Peak propulsive force on Day 3 was significantly higher than that on Day 1 ($p = .007$) (Table 3).

Discussion

To our knowledge, this is the first study to examine how DOMS in the Gmax affects hamstrings during sprinting. In support of our hypothesis, it was confirmed that some kinematic, kinetic, muscle activity and pressure pain parameters changed between Day 1 and 3; it was confirmed that hip extension peak strength was significantly lower on Day 2 and Day 3 than it was on Day 1. Simultaneously, pressure pain for Gmax and Gmed on Day2 and 3 were significantly lower than those for Day 1. Again, Maximal

1 muscular voluntary contraction and muscle soreness are considered to effectively
2 quantify the degree of DOMS (8, 35, 43). Also, considering for significantly higher
3 muscle activity for hamstring(BF) during sprinting on Day 3 as well as no difference for
4 maximal sprint time between Day 1 and Day 3, it is plausible to assume that hamstring
5 was highly activated especially when it contract eccentrically to decelerate the lower
6 limb during the late swing phase, mainly due to the loss of function of Gmax affected
7 by DOMS.

8 Hip flexion angle on Day 3 was significantly lower than it was on Day 1,
9 although knee flexion angle on Day 3 was significantly higher than it was on Day 1.
10 Those findings are consistent with the findings by Small et al. (34) who examined the
11 effect that fatigue has on lower limb kinematics during sprinting for soccer players and
12 reported that hip flexion and knee extension were significantly reduced during the
13 terminal swing phase. They also reported that those kinematic alterations, decreased hip
14 flexion and knee extension angles, cause hamstrings to shorten, potentially leading to
15 increased risk for hamstring strains (34). Another point to note, Gabbe et al. (13)
16 conducted a prospective study with rugby players and reported that if the hip flexion
17 angle is reduced by one degree, the risk of hamstring tears increases by 15%. In line
18 with this finding, we found decreased hip flexion angle on Day 3. The possible
19 explanation for this is that, as one of the typical symptoms of DOMS is decreased range
20 of motion (28), DOMS-affected Gmax may cause decreased hip flexion angle. Thus, the
21 altered kinematic movements observed in the current study, especially decreased hip
22 flexion, may potentially be linked to the reported risk indicator (13) associated with
23 hamstring strains.

24 We found that VM, BF, and Gmax muscle activity levels on Day 3 were
25 significantly higher than those on Day 1. For sprinting, the basic roles of the Gmax and
26 the hamstrings during the terminal swing phase are to work together to slow the lower
27 limb (deceleration of hip flexion) (41). In this study, we confirmed peak strength for
28 Gmax was decreased mainly due to DOMS on Day 3, although its muscle activity was
29 significantly higher than the one on Day 1 during sprinting. This phenomenon seemed
30 to be the compensatory response of DOMS-affected Gmax as well as BF, which tried to
31 increase muscular output to control the lower limb. This finding, higher hamstring
32 activation, is consistent with the study by Martinez (24) which examined how restricted
33 hip flexion effects on Gmax during squat movements focusing on the effect of

1 synergetic dominance by hamstrings. As further consideration for this, since knee
2 flexion angle during the late swing phase was increased on Day 3, BF was likely to
3 work harder to eccentrically control knee extension as well as contributed to muscular
4 output for hip flexion, which may explain increased BF muscle activity on Day 3.

5 Taken those alterations for kinematic and muscular activities collectively, our
6 findings may indicate that decreased Gmax peak strength and hip flexion, together with
7 increased knee flexion during the late swing phase cause increased hamstring activity to
8 decelerate the lower limb to compensate for the loss of function of the Gmax. This
9 compensatory strategy seems to be synergetic dominance, increasing the load on
10 hamstrings in order to eccentrically control both knee extension and hip flexion and
11 may result in faster fatigue of hamstrings.

12 We found that the propulsive force on Day 3 was significantly higher than it
13 was on Day 1. Perhaps related to this event, there was no significant difference between
14 the sprint times of day 1 and day 3, although the peak strength of hip extension was
15 significantly lower than the ones on day 1. Morin et al. (27) reported that the
16 participants, who had highly activated hamstring just before ground contact, showed
17 higher horizontal GRF closely related to sprint performance(4). Furthermore,
18 Montgomery et al.(26) found that knee extensors are important in producing forward
19 propulsive force in the late swing while running. Given all of those, in this study,
20 increased VM and BF activity were confirmed during the late swing phase, which is a
21 plausible explanation for the increased the propulsive force on Day 3, resulting in no
22 time differences in sprint time between Day 1 and Day 3.

23 Some limitations must be taken into consideration. First, Blackburn et al.
24 (4)reported that there are structural differences in the hamstrings between men and
25 women (such as size and muscle cross-sectional area). In general, males' hamstrings
26 have more muscle mass and larger cross-sectional areas than those in females. Thus,
27 females tend to have less hamstring stiffness than males, indicating that there is likely a
28 gender difference in how hamstring lengths change in response to joint perturbation.
29 Since this study was conducted with only male participants, future experiments should
30 be conducted with both females and males, focusing on gender differences. Second, as
31 described earlier, the experiment was slightly different from the one conducted by
32 Heiderscheit et al. (15) to identify the time of the hamstring strain. In this study, the
33 participant sprinted on a flat surface, whereas in the other study (15), participants

sprinted on a surface with a 15% slope. Thus, these methodological differences must be considered when interpreting the results of this study. Third, this study mainly aimed to examine how DOMS-affected Gmax have an effect on hamstring during late swing phase. However, since we chose a single leg squat, which is a closed-kinetic chain exercise, Gmax seemed to be not only affected, but other muscles such as Gmed and VM seemed to be also affected by DOMS. Thus, further research using an open-kinetic chain exercise for Gmax may be warranted. Lastly, because the participants in this study were healthy active men, it remains unclear whether our findings can be applied to athletic populations, such as football or basketball players; a future study may be required to explore this population.

Practical Applications

As hypothesized, when the Gmax was dysfunctional because of DOMS, changes in kinematics, muscle activity, and kinetics occurred during sprinting. This compensatory strategy seems to be synergetic dominance, increasing the load on hamstrings for eccentric contraction of knee extension and hip flexion, since hamstrings, as biarticular muscles, and the Gmax work together to control the lower extremity during the late swing phase.

Of note, decreased hip flexion angle and increased BF as well as Gmax activity may potentially be linked to increased risk of incurring a hamstring injury. Thus, as the practical applications drawn from the current study, careful planning is required, especially for speed training such as sprinting and agility training, etc., approximately 48 hours after exercises that emphasize the Gmax muscle (e.g., back squats or single leg squats). Also, both objective and subjective assessment of muscle soreness, careful warm-up, and gradual increase in intensity and speed can be an effective method to prevent hamstring strains.

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Conflict of Interest

The authors have no conflicts of interest to report.

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3 **Legends to figures**

4 **FIGURE 1.** DOMS-induced exercise: (a) Participants held a 10 kg dumbbell while
5 performing a single-leg squat with their dominant leg in front and the other leg behind
6 and elevated with the toes resting on the top surface of the box. (b) Then, participants
7 flexed the knee and hip of the dominant leg until their thigh was parallel to the floor.

8 **FIGURE 2.** Peak strength (mean $\pm$ SE) after DOMS-induced
9 exercise from Day 1 to Day 3. *P < 0.05 significantly different from Day 1 †P < 0.05
10 significantly different from Day 2

11 **FIGURE 3.** Maximal sprint times (mean $\pm$ SE) for Day 1 and Day 3. There was no
12 significant difference (P > 0.05) between Day 1 and Day 3.

13 **FIGURE 4.** EMG activity (mean $\pm$ SE) during late swing phase for 130 ms. Abbreviation:
14 VM, ; BF, ; Gmax, ; Gmed, . **P < 0.05 *P < 0.01

Table 1. Outline of the experimental procedure

Day 1	Day 2	Day 3
Warming up (5 min)	Warming up (5 min)	Warming up (5 min)
algometer	algometer	algometer
Hand-held dynamometer measurements	Hand-held dynamometer measurements	Hand-held dynamometer measurements
Jogging (5 trials)		Maximal sprints (6 trials)
Maximal sprints (6 trials)		
DOMS-causing exercise		
Abbreviation: DOMS, delayed onset muscle soreness.		

Table 2. Late swing phase kinetic and kinematic variables (mean $\pm$ SE for 130 ms interval)

variables	Day 1				Day 3				Effect size (r)	P value
	Mean	SE	Median	5th and 95th percentile	Mean	SE	Median	5th and 95th percentile		
Hip flexion angle(°)	68.2	0.79	70.1	56.2 - 78.7	63.0	1.64	66.80	30.8 - 79.0	0.23	< .001*
Hip flexion velocity (°/s)	76.9	24.21	51.6	-239.8 - 515.3	85.5	27.21	37.80	-235.6 - 553.3	0.03	0.74
Hip flexion/extension moment (N · m)	210.6	10.85	174.9	115.2 - 413.8	190.5	10.31	159.90	66.4 - 404.3	0.12	0.26
Knee flexion angle(°)	23.4	1.06	21.2	10.1 - 41.9	27.2	1.35	26.80	5.3 - 47.3	0.26	< .001*
Knee flexion velocity (°/s)	-924.0	26.52	-910.5	-1305.9 - -498.2	-898.3	30.95	-863.40	-1421.1 - -292.3	0.15	0.16
Knee flexion/extension moment(N · m)	-90.1	3.27	-92.1	-127.2 - -64.2	-87.3	3.04	-90.30	-125.8 - -45.7	0.12	0.25

*P<0.01

Table 3. Stance phase kinetic variables (mean $\pm$ SE)

variables	Day 1				Day 3				Effect size (r)	P value
	Mean	SE	Median	5th and 95th percentiles	Mean	SE	Median	(5th and 95th percentiles)		
Peak vGRF(BW)	28.7	0.85	25.0	18.1-47.6	27.80	0.98	23.5	16.3-48.4	0.13	0.21
Peak Breaking Force(BW)	6.20	0.20	6.0	3.1-10.5	6.85	0.35	4.9	2.0-11.5	0.19	0.06
Peak Propulsive Force(BW)	3.29	0.13	3.5	5.1 - 1.4	3.37	0.12	3.5	6.6-2.1	0.27	< .001*

All values are absolute; *P<0.01

Outline of the experimental procedure

Day 1	Day 2	Day 3
Warming up	Warming up	Warming up
Hand-held dynamometer measurements	Hand-held dynamometer measurements	Hand-held dynamometer measurements
Jogging (6-10times)		Maximal sprints (6-10times)
Maximal sprints (6-10times)		
DOMS-induced exercise		

Figure 1

Maximal sprint time (Mean $\pm$ SE) between day1 and 3

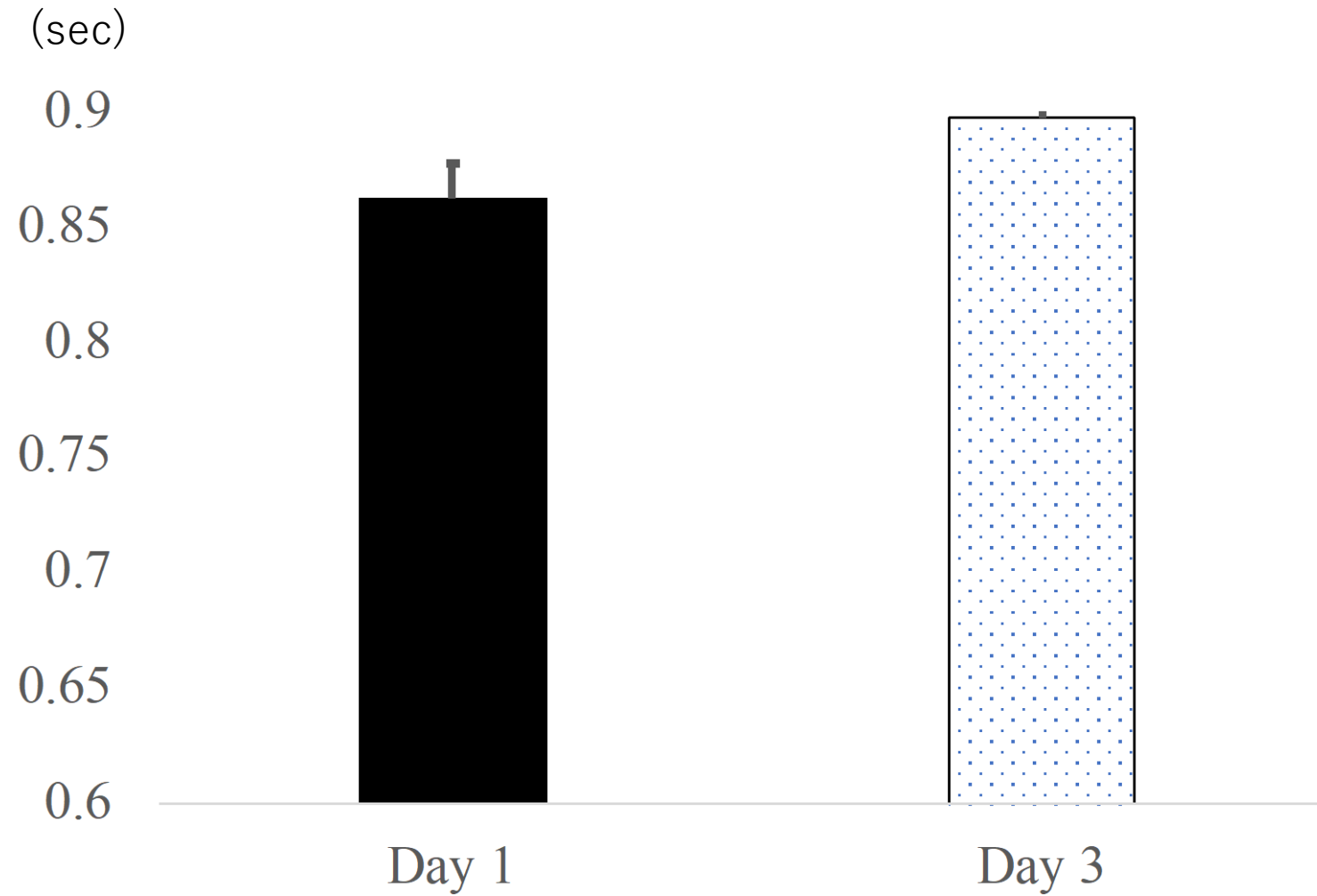


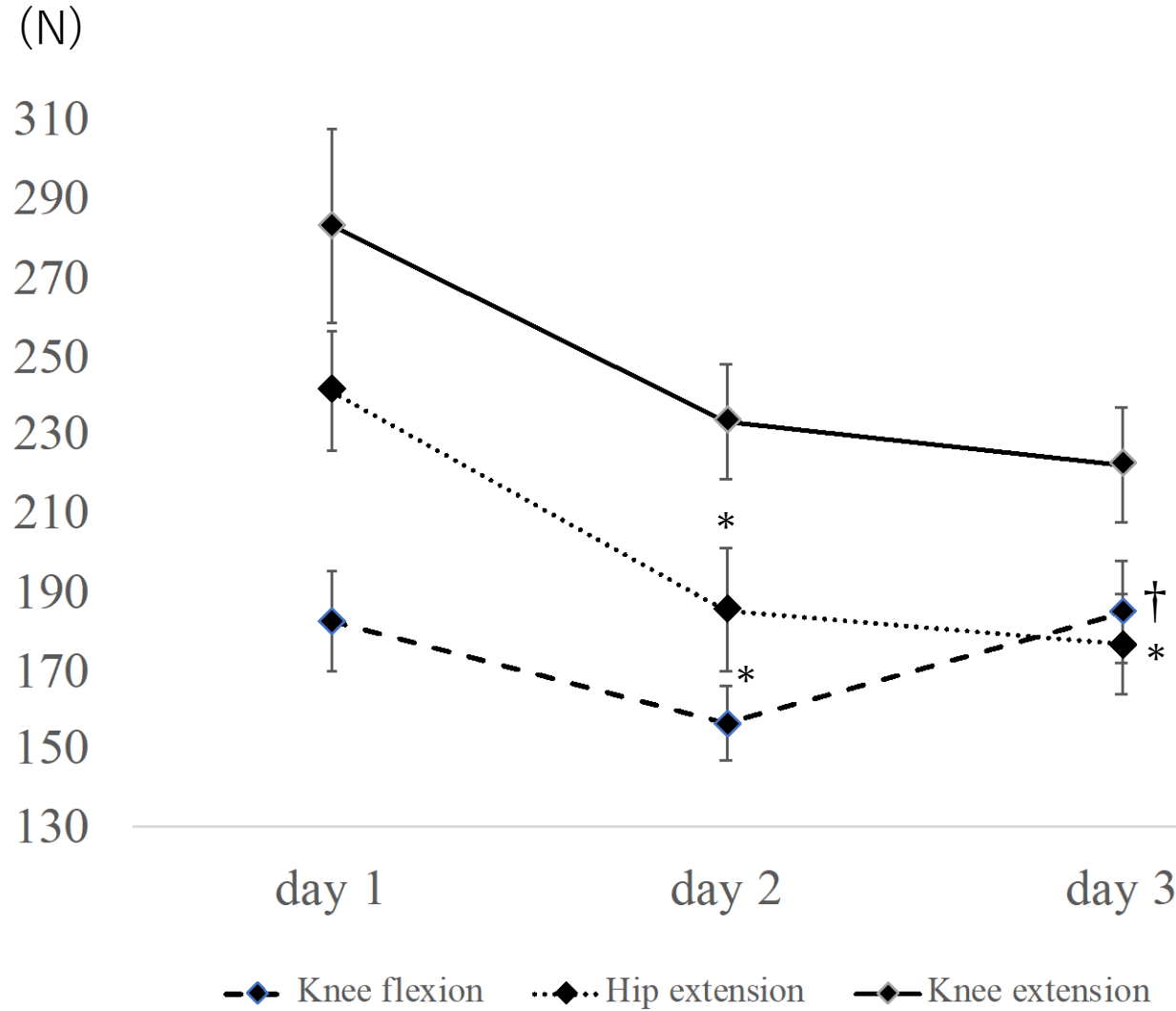
Figure 2

DOMS-induced exercise



Figure 3

Peak strength (Mean $\pm$ SE) after DOMS-induced exercise from day1 to 3



*P<0.05 significantly different from day1 † P<0.05 significantly different from day2

Figure 4

EMG activities (Mean $\pm$ SE) during late swing phase for 130ms

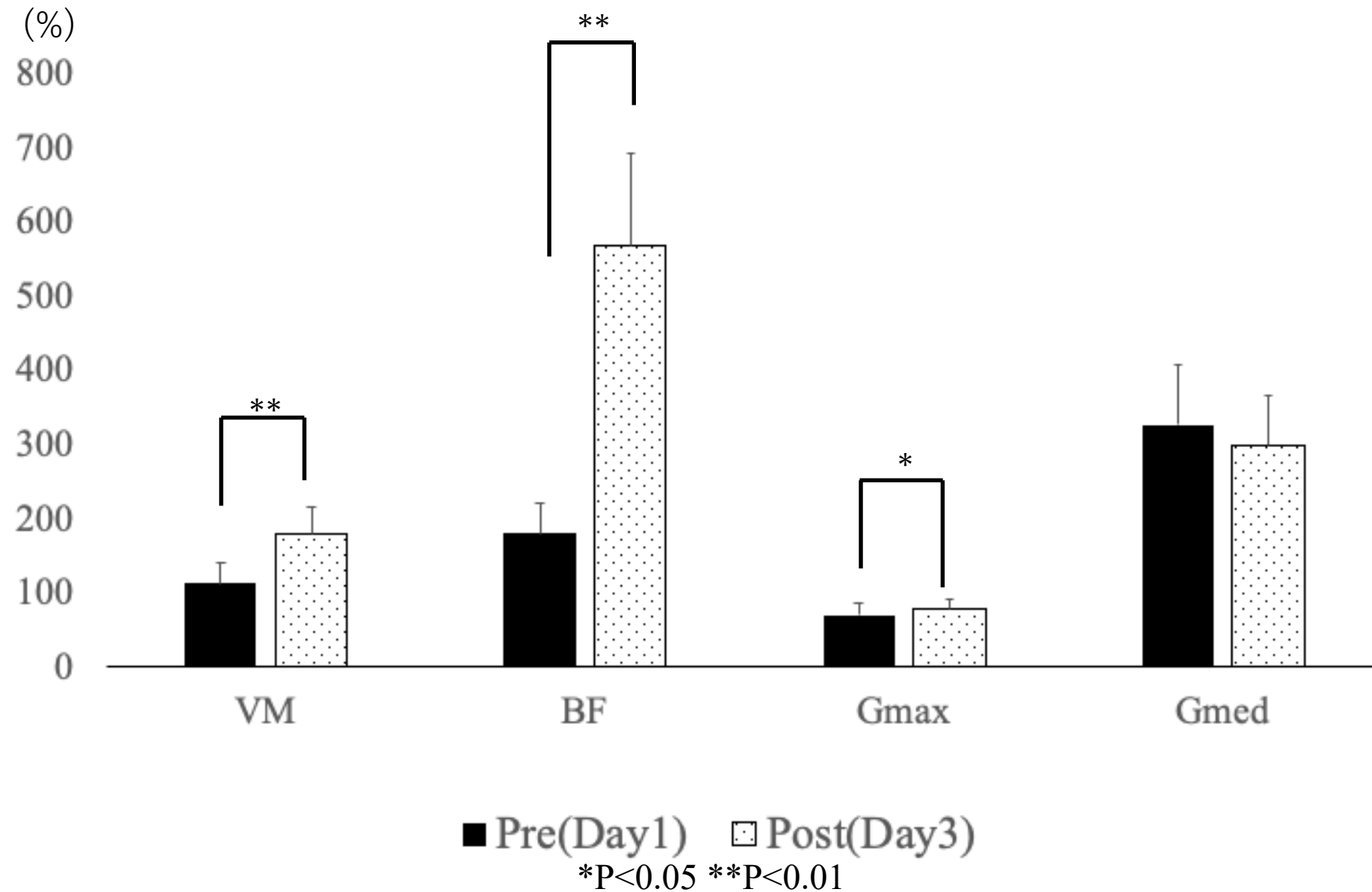


Figure 5