Postural balance challenge in isometric squat position: Hammerobics-synchronized squat

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Article

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Abstract

BACKGROUND: Perturbation exercises enhance lower limb and trunk muscles, and adding swing perturbation while loading during exercise might improve muscle activation or strength.

OBJECTIVE: To check variations in trunk and lower limb muscle activity during conventional isometric squats, and whether it will change with or without swing using the Hammerobics-synchronized squat method.

METHODS: Twelve healthy men participated in this study. Activities for the abductor hallucis, tibialis anterior, tibialis posterior, peroneus longus, rectus femoris, biceps femoris, semitendinosus, gluteus maximus, multifidus, and internal oblique muscles were measured using surface electromyography during a Hammerobics-synchronized squat and conventional isometric squat. Muscle activities were statistically compared between squat methods.

RESULTS: Hammerobics-synchronized squats significantly activated the abductor hallucis, tibialis anterior, tibialis posterior, peroneus longus, semitendinosus, and multifidus muscles, in both phases, compared with the conventional isometric squats.

CONCLUSIONS*:* The Hammerobics-synchronized squat exercise can be considered for trunk and foot stability exercise.

Introduction

Motor control, which relies on constant communication between the motor and sensory systems, is critical for spinal posture, stability, and movement [1]. Proprioception challenges for activities such as using unstable surfaces increase on trunk muscles, potentially improving core stability and balance [2]. Neuromuscular control plays an essential role in trunk stability and lower back pain (LBP) prevention and rehabilitation [3]. Deep trunk muscles, such as the transversus abdominis and multifidus (Mul) muscles, are key trunk stability muscles, although they demonstrate delayed muscle activity in people with chronic LBP. [4]. Schäfer et al. examined unstable situations using internal and external perturbation experimental tests for rowers. Sport-specific movements and postures were performed precisely in the squat and rowing positions using an unstable surface, water-filled pipe, or pushing from a third party [5]. Perturbation-based intervention with 224 exercises (using soft pads, balance cushions, BOSU balls, inverted BOSU balls, Swiss balls, slashpipes, and sling trainers) for a year in adolescent athletes increased trunk muscle strength, reduced strength imbalances between the flexor and extensor muscles, and decreased low-back pain intensity [6]. Furthermore, utilizing unstable situations in exercises can enhance lower limb and trunk muscle stability. [7]. Using such water-filled equipment or sandbags enhances lower limb and trunk stability muscles during squatting or clean and jerk exercises for the stabilizing task [8]. Several studies have examined muscle activity according to the swinging perturbation movement in exercise to determine whether muscles can activate effectively. Saeterbakken et al. compared a regular bench press by adding pendulums that swing forward/backwards [9]. Van Gelder et al. examined single-or double-arm kettlebell swinging exercises in the anteroposterior direction to determine whether muscle activation can be increased in the gluteus maximus, gluteus modius, and biceps femoris muscles [10]. Kettle-bell swing exercises improve both maximum and explosive strength in a six-week program [11]. Based on these points, adding swing perturbation during loading during exercise might improve muscle activation or strength.

The squat exercise is the most well-known and regularly used exercise to activate thighs and numerous muscle groups, not only limited to sports activity but also for rehabilitation to strengthen lower-body muscles and connective tissue after joint injury. [12]. For an intervention study, the exercise program with high loads, performed twice a week for eight weeks, demonstrated leg strength and power, and was enhanced for young athletes with back half-squat exercises [13]. Isometric squats are also commonly used for examining the lower limbs [14]. Adding unstable situations such as swinging weight during squat exercises might enhance the effect of squat exercises to improve lower limb and trunk muscle strength.

Hammerobics™ exercises are perturbation exercises that require postural stability and muscle coactivation [15]. Exercise is derived from the athletic event of hammer throwing, which utilizes the concept of parametric excitation. The theoretical system of parametric excitation can be understood by considering a hula-hoop model that uses such an energy-pumping system [16, 17]. Hammerobics-synchronized squat (HSS) is an exercise that uses swinging perturbation movement in the anteroposterior direction during isometric squats, with competitive hammers attached to each side of the Olympic lifting bar while maintaining posture [15]. Owing to the perturbation of the hammer movement during HSS, body posture is required to hold the position and is likely to activate the lower limbs, foot, and trunk muscles. However, no such study has examined the activation of the trunk and lower limb muscles during perturbation-based stabilization training in HSS.

A present study compared the conventional isometric squat (CIS) with HSS, which added hammers swing movement in the anteroposterior direction with CIS, and examined how the trunk and lower limb muscles are activated. For the main task of the HSS, voluntary effort was made in response to the externally applied mechanical loading (hammers movement) while maintaining the swing motion. We hypothesized that the abductor hallucis (Abd H), tibialis anterior (TA), tibialis posterior (TP), and peroneus longus (PL) muscles will be activated in the HSS and that trunk muscles, including the Mul muscle, will demonstrate higher activation with the HSS than with the CIS.

Methods

Participants

Twelve healthy men, aged 19–45 years, participated in this study. All the participants were physically active and engaged in at least three practices per week. Before the experiment started, all participants who had severe injuries in the last three months or pain on the day of examination were eliminated. The participants were instructed to stop when they felt pain during any of the test phases. None of the participants were interrupted due to injury or discomfort during the examination. This laboratory study used a within-participant repeated-measures design. Muscle activity was the dependent variable, and the form of exercise was the independent variable. The study was approved by the Research Ethics Committee of Tokyo Medical and Dental University (research protocol identification number: M2018-162) in 2018 and followed the principles of the Declaration of Helsinki (52nd World Medical Association General Assembly Edinburgh, Scotland, October 2000) for medical research involving human subjects. All participants provided written informed consent to study participation.

Hss

HSS is a type of isometric squat exercise in which the two hammers are swung simultaneously in the same direction. This exercise creates anteroposterior and vertical movements by swinging hammers that are hung with wires at each end of an Olympic lifting bar (Fig. 1). During exercise, the amplitude of the oscillated hammers was maintained within 90° of the vertical plane for safety [15]. To perform HSS, maintaining an isometric squat position with upright upper body posture is necessary while moving the hammers steadily in the anteroposterior direction. It should be noted that the focus of the exercise is not to see how much amplitude can be applied to the swinging of the hammers, but to maintain the amplitude of swing without disrupting the rhythm of the hammers, using minimal body motion, postural change, and rhythm.

Cis

CIS is an isometric exercise using a barbell with the same weight as HSS, in which the individual remains in the squat position to keep the hip and knee angles relatively flexed.

Exercise task and setup

For the setup, in HSS, a 7.26-kg hammer (φ: 116.5 mm; NISHI Athletics Goods Co. Ltd., Tokyo, Japan) was attached to each end of the Olympic lifting bar by looping the hammer wire. The total length of the equipment from the bottom of the ball to the wire was 0.5 m. Weight set up is described in Table 1. The weight of the equipment was set according to the participant's body weight range. In CIS, the total weight of the barbell and Olympic lifting bar was adjusted to be equal to the weight of each participant's HSS. The participants were asked to perform HSS and CIS exercises while the knee angle was maintained at 60° for every trial. Postural instruction was provided based on the examiners' observation to maintain the starting posture. Each exercise type was performed in two trials. In each HSS trial, we recorded ten swings once the swings of the hammers were in the control group. Three swings from each trial were used for the experimental analysis. In each CIS trial, we recorded 10 s when the participant was in the initial squat posture. Between data on 4.01–7.00 s were used. The hammer movement was captured by a high-speed camera, and the HSS movement was divided into two phases. We defined hammer movement with HSS

(Figure xx) as front-to-back (FB) and back-to-front (BF). In the FB phase, the hammer moved from the front side of the participants after reaching the highest point, and then to the back side at the highest point. In the BF phase, the movement of the hammer is the opposite of that in the FB phase, from the back side at the highest to the front side at the highest.

Wireless surface EMG

Muscle activity was measured during the exercise task using surface EMG (Ultium EMG, EM-U810M8, Tele Myo2400, Noraxon USA Inc., Scottsdale, AZ, USA) and recorded at 2000 Hz with band-pass filtering (10–500 Hz) on a personal computer (EM-P5, Noraxon) using a receiver (EM-U880, Noraxon). The EMG system and the high-speed camera were synchronized. Prior to attaching electrodes, the skin was shaved, abraded, and cleaned with alcohol. The electrode application site for EMG was determined according to previous studies [18, 19, 20] and guidelines by SENIAM (URL: http://www.seniam.org/). Surface electrodes (Ambu, Blue Sensor M-00-S, Ballerup, Denmark) were attached 35 mm apart to the Abd H, TA, TP, PL, rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), gluteus maximus (GM), Mul, and internal oblique muscles (IO) on the right side (Fig. 2). The electrodes for each muscle were attached parallel to the muscle fibers. The skin impedance was confirmed to be < 5 kΩ before each measurement [21], and all data were rectified and smoothed using a root-mean-square algorithm with a 50-ms time reference. This experimental test was not used for the comparison of muscle activity levels between the muscles. An amplitude comparison of the signals from a given muscle was conducted between the two exercise tasks within an individual in the same session, strictly under the same experimental conditions, and without altering the EMG electrodes [22, 23]. The average value used for analysis (μV-s) was calculated and averaged over the three complete swings during the exercise task, and the mean values were used for analysis [24].

Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was performed to confirm normality. Depending on the normality of the distribution, a one-way analysis of variance or the Kruskal–Wallis test was used to examine the difference between the exercise tasks. The post hoc test for one-way analysis of variance or Kruskal–Wallis test was the Bonferroni correction. A p-value < 0.05 was considered significant in an *a priori* power analysis. Data are expressed as the median (interquartile range).

Results

The median and interquartile range of muscle activity and statistical analysis results for each exercise task are described in Tables 2 and 3 and Fig. 3. For the HSS, the activation of the Abd H, TA, TP, PL, ST, and Mul muscles were significantly activated in both FB and BF phases compared with CIS.

Discussion

In this study, the muscle activation differed between the two exercises. The HSS strongly activates the Abd H, TA, TP, PL, ST, and Mul muscles compared with the CIS.

Perturbation-based training is effective for trunk stabilization, and it reduces pain. Schäfer et al. examined instability situations using an unstable surface or water-filled pipe or pushing from a third party and stated that perturbation-based trunk stabilization training is possibly effective in improving the physical function of the lower back in elite rowers. [5]. Perturbation-based intervention (using soft pads, balance cushions, BOSU balls, inverted BOSU balls, Swiss balls, slashpipes, and sling trainers) for a year in adolescent athletes reduced strength imbalances and LBP intensity decreased [6]. The Mul muscle contributes to the stability of the lumbar spine and plays a role in controlling intersegmental motion [25]. In a previous study, the HSS demonstrated significant activation of the Mul muscle by perturbation-based intervention.

The foot is a complex structure that plays an essential role in maintaining static and dynamic posture. Intrinsic and extrinsic muscles control the movement and stability of the foot arch [26]. Because HSS requires the center of pressure to shift forward and backward, the TP, TA, and PL, which are fundamental muscles to control the foot arch dynamically, increased the muscle activities with HSS. Exercise programs improve intrinsic and extrinsic foot muscles to help sports injuries, rehabilitation, and prevent fall risks. Short foot exercise is a proper strengthening exercise activating the foot muscles, especially the Abd H [27, 28]. Short-foot exercises can help strengthen the Abd H muscle in individuals with pes planus [29]. Kulig et al. have reported that TP training with orthoses could improve foot functional index scores including pain and disability [30]. Selective training for the tibialis posterior with iliopsoas stretching demonstrated prominent improvements in dynamic balance and static arch height compared with conventional towel curl exercises in participants with pronated feet [31]. The 4 to 8 months of training for the foot exercise program was effective for running-related injuries risk for 2.42 times lower than that of the control group within 12 months for recreational runners [32]. Further, 6 weeks of short-foot exercise intervention reduced navicular drop, foot pronation, foot pain, disability, and increment in plantar force of the medial midfoot in pes planus [33]. Impairing balance increases the risk of falls in older adults. Foot/ankle characteristics, sensorimotor function, balance, and functional ability are associated with the risk of falls. The intervention of a program that improves the strength and flexibility of the foot muscles can reduce the risk of falls [34]. However, the movement of the foot and ankle joints is complicated, and some people have difficulty in effectively training the internal and external muscles of the foot because of deformation or pain. Therefore, it is important to devise a method that can effectively train the intrinsic and extrinsic muscles of the foot, and the results of this study showed important data in that the HSS can train these muscle groups unconsciously.

In a present study, HSS significantly activated intrinsic and extrinsic foot muscles without the intention of moving the foot fingers by hammer perturbation.

A present study added an unstable situation with hammer perturbation during a squat called the HSS. In postural stability against perturbation, the activity of muscle groups related to the lumbar spine, foot, and ankle joint tended to be increased rather than the muscle groups associated with the hip joint and pelvis stability. The foot and Mul muscles are significantly activated without changing positions, trying to move the hip or knee joint angles or foot toes. Although this exercise shows muscle activity at BF and FB phases differently, it requires a switching function on muscle activation while swinging the hammer steadily in the squat position. Learning the timing of on and off for the muscle activation, and this movement may potentially improve the coordination of the muscles around the trunk, hip joints, knee joints, and ankle joints can develop coordination on the whole body. For clinical implications, the HSS exercise can be a candidate for core and foot stability exercise, and it could be a valuable exercise even for patients with limited joint movement.

This study had some limitations. First, we only examined participants in a single body position, while in the isometric squat position. Different body positions can lead to different muscle activation. Second, we only compared the anteroposterior direction of the hammer movement. Different hammer movements can result in different muscle activation outcomes. Lastly, we did not normalize the EMG signals because data were collected/compared in the same participant during the same session within a short period [24]. Therefore, these factors should be considered and analyzed in future studies.

Future studies can examine muscle activities on different Hammerobics exercises by changing the weight or length of the wire or the direction of the hammers.

Conclusion

The TA, TP, Abd H, and PL muscles were significantly more activated during HSS compared with CIS. The HSS exercise can be considered for trunk and foot stability exercise.

Declarations

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Author Contributions

KM conceived and planned the conception. KM, TO, HA, DY, carried out the performance of the work. KM, KK,TO, HF, KH, SM planned and carried out the interpretation of the manuscript. KM, KK, TO, HA, KH, SM, DY contributed to preparation of the manuscript. KM, KK, TO, HA, contributed to the revision for important intellectual content. KK, KY took the lead in supervision.

Competing interests

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Tables

Table 1: Weight setup.

Weight range	Barbell weight
≤110 kg	Shaft (20 kg) + 2 hammers (7.26 kg each) + 2 weights (12.5 kg each) = 59.5 kg
95 kg–109 kg	Shaft (20 kg) + 2 hammers (7.26 kg each) + 2 weights (10 kg each) = 54.5 kg
80 kg–94 kg	Shaft (20 kg) + 2 hammers (7.26 kg each) + 2 weights (7.5 kg each) = 49.5 kg
65 kg–79 kg	Shaft (20 kg) + 2 hammers (7.26 kg each) + 2 weights (5 kg each) = 44.5 kg
≤64 kg	Shaft (20 kg) + 2 hammers (7.26 kg each) + 2 weights (2.5 kg each) = 39.5 kg

Table 2 The activity of each muscle in BF, FB and CIS

Muscles	BF median (interquartile range)	FB median (interquartile range)	CIS median (interquartile range)
Abductor hallucis	80.55 (59.31)	77.08 (60.93)	17.1 (38.59)
Tibialis anterior	130.5 (88.05)	208.5 (100.11)	75.87 (63.58)
Tibialis posterior	85.6 (76.61)	84.18 (45.41)	34.85 (26.22)
Peroneus longus	100.9 (38.54)	86.9 (35.9)	32.4 (34.03)
Rectus femoris	177.75 (104.38)	181.75 (58.11)	131.44 (56.92)
Biceps femoris	56.05 (13.56)	56.78 (16.91)	41.58 (26.01)
Semitendinosus	57.5 (45.2)	43.4 (52.18)	26.26 (15.78)
Gluteus maximus	41.95 (77.23)	42.85 (81.31)	26.6 (26.29)
Multifidus	140.25 (49.88)	145.75 (56.25)	100.93 (25.5)
Internal oblique	31.6 (35.61)	29.65 (34.98)	17.03 (18.18)

BF, back-to-front; FB, front-to-back; CIS, conventional isometric squat.

Table 3: The results of statistical analysis

Muscles	Comparison between variables	One-way ANOVA F-value or Kruskal-Wallis χ^2	One-way ANOVA or Kruskal-Wallis p-value	Post hoc p-value * $p < 0.05$ [a]	Cohen's d (95% confidence interval)
Abductor hallucis	BF vs. FB	11.311	* 0.003	0.832	0.335 (-0.482 to 1.128)
	BF vs. CIS			* 0.006	1.400 (0.465 to 2.239)
	FB vs. CIS			* 0.022	1.180 (0.277 to 2.002)
Tibialis anterior	BF vs. FB	14.710	* < 0.001	0.280	-0.957 (-1.765 to -0.082)
	BF vs. CIS			0.270	1.432 (0.492 to 2.274)
	FB vs. CIS			* < 0.001	2.143 (1.077 to 3.060)
Tibialis posterior	BF vs. FB	16.114	* < 0.001	0.768	0.522 (-0.308 to 1.317)
	BF vs. CIS			* < 0.001	1.419 (0.481 to 2.259)
	FB vs. CIS			* 0.005	1.535 (0.579 to 2.386)
Peroneus longus	BF vs. FB	19.182	* < 0.001	0.239	0.589 (-0.247 to 1.385)
	BF vs. CIS			* < 0.001	2.390 (1.275 to 3.341)
	FB vs. CIS			* 0.002	1.828 (0.822 to 2.708)
Rectus femoris	BF vs. FB	0.497	0.780	0.768	-0.229 (-1.024 to 0.582)
	BF vs. CIS			1.000	-0.043 (-0.842 to 0.758)
	FB vs. CIS			0.862	0.218 (-0.592 to 1.013)
Biceps femoris	BF vs. FB	1.617	0.214	0.998	-0.023 (-0.822 to 0.778)
	BF vs. CIS			0.291	0.631 (-0.209 to 1.428)

	FB vs. CIS			0.226	0.674 (-0.170 to 1.472)
Semitendinosus	BF vs. FB	6.731	* 0.004	0.666	0.302 (-0.513 to 1.096)
	BF vs. CIS			* 0.004	1.663 (0.685 to 2.526)
	FB vs. CIS			* 0.032	1.153 (0.253 to 1.973)
Gluteus maximus	BF vs. FB	5.407	0.067	0.955	0.009 (-0.791 to 0.809)
	BF vs. CIS			0.107	0.991 (0.112 to 1.801)
	FB vs. CIS			0.121	0.963 (0.088 to 1.772)
Multifidus	BF vs. FB	6.731	* 0.004	0.999	0.016 (-0.784 to 0.816)
	BF vs. CIS			* 0.009	1.425 (0.486 to 2.266)
	FB vs. CIS			* 0.010	1.377 (0.446 to 2.214)
Internal oblique	BF vs. FB	4.092	0.129	0.955	-0.046 (-0.845 to 0.756)
	BF vs. CIS			0.193	0.606 (-0.232 to 1.403)
	FB vs. CIS			0.193	0.614 (-0.225 to 1.410)

FB, front to back; BF, back to front; CIS, conventional isometric squat.
a: adjusted p-value by multiplying the original p-value by three.

Figures

Figure 1

Explanation of Hammerobics-synchronize squat and the conventional isometric squat.

a: Hammerobics hammer setup. **b**: Hammerobics synchronized squat. **c**: Conventional isometric squat.

Figure 2

The electrode application site for electromyography.

a: medial view of the lower leg, **b**: anterolateral view of the lower leg, **c**: anterior view of the upper leg, **d**: posterior view of the upper leg, **e**: anterior view of the abdomen, **f**: posterior view of the lower back. A: Tibialis posterior, B: Abductor hallucis, C: Peroneus longus, D: Tibialis anterior, E: Rectus femoris, F: Semitendinosus, G: Biceps femoris, H: Internal oblique, I: Multifidus, J: Gluteus maximus

Figure 3

The median and interquartile range of muscle activity during each exercise task.

BF, back-to-front; FB, front-to-back; CIS, conventional isometric squat.