

#### **Original Research**

# Examining the effect of transcranial direct current stimulation on the dominant motor cortex in the indirect measurement of physical ability

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#### Abstract

**Background**: The effects of transcranial direct current stimulation (tDCS) on specific sports skills have received extensive attention, however, it is difficult to accurately determine its effect on physical performance due to the complexity of the tasks. The objective of this study was to investigate the effects of uni-hemispheric anodal tDCS of the motor cortex (M1) on the indirect measurement of physical ability in healthy men. **Methods**: Thirteen healthy, right-leg-dominant men aged between 21 and 32 years (26.53 ± 2.73 years) participated in two different experimental conditions in a randomized, single-blinded crossover design: anodal stimulation (a-tDCS) and sham-tDCS (2 mA for 20 minutes targeting the left M1 contralateral to dominant leg). Before and immediately after the tDCS stimulation, participants completed the standing long jump (SLJ) and sidestep test (SST), and their blood pressure and heart rate were checked for the safety of tDCS application. **Results**: No significant difference was observed between a-tDCS and sham-tDCS ( $F_{(1,24)} = 0.02$ , p = 0.86,  $\eta_p^2 = 0.001$ ) on SLJ. Also, no significant changes in SLJ were observed between pre- and post-stimulation sessions for both conditions ( $F_{(1,24)} = 0.57$ , p = 0.45,  $\eta_p^2 = 0.024$ ). Significant changes in SST were not observed throughout the experiment sessions for both stimulation conditions ( $F_{(1,24)} = 0.12$ , p = 0.73,  $\eta_p^2 = 0.005$ ). **Conclusions**: The uni-hemispheric a-tDCS applied over the M1 for 20 minutes may not be a valuable tool to obtain the physical performance benefits from the tasks that require bilateral lower limb power output, such as SLJ and SST.

Keywords: Physical performance; tDCS; Primary motor cortex (M1); Agility

## 1. Introduction

Several studies using transcranial direct current stimulation (tDCS) have reported positive physical performance effects in direct measurement of physical performance such as muscular strength [1,2] and endurance [1,3]. Direct measurements of muscle strength and endurance using a singlejoint movement and cycling tasks permit a more controlled examination of the physiological effects of tDCS. However, some studies have suggested that indirect measurement of physical abilities, such as agility and countermovement jump (CMJ), may better reflect real sports situations, and thus, may provide the necessary ecological validity for use in field conditions [4].

More recently, studies have investigated various indirect measurements of physical ability to test the positive effects of tDCS, such as the CMJ and agility test for specific sports skills [2,4,5]. Lattari *et al.* [2] found a large increase in CMJ height (i.e., ~11%) after bilateral anodal stimulation (a-tDCS) of the primary motor cortex (M1) which can increase excitation, through tonic depolarization of the membrane resting potential. In addition, Romero-Arenas *et al.* [4] replicated the procedure proposed by Lattari *et al.* [2] and applied it to a modified stimulation area (dorsal lateral prefrontal cortex; DLPFC). Although they did not find a significant change in CMJ performance and muscle peak power after stimulation of the DLPFC, their results confirmed the prominent function of M1. However, the use of bilateral stimulation montage in Lattari *et al.*'s [2] study did not consider the effect of dominant hemisphere stimulation. Although direct measurement studies regarding the knee extensor force revealed that stimulation of the dominant hemisphere generates a positive effect of tDCS [6], the unilateral stimulation effect of dominant M1 in the indirect measurement of physical ability, such as CMJ and agility remains unclear.

A recent tDCS study used the basketball dribbling test in which the participants had to move sequentially with predetermined spots and directions as an agility test for the indirect measure of physical ability [5]. The time taken to complete the ball-dribbling test was measured before and after the application of 20 minutes of 1 mA a-tDCS over the dominant M1. The results revealed that basketball-specific dribbling and agility improved after anodal-tDCS over the dominant M1 but not after sham-tDCS (s-tDCS). The key aspect of this complex motor task is automatized motor control that allows the participants to perform sequentially according to the predefined order as quickly as possible, with a greater degree of automaticity being linked to implicit motor memory [7]. Increased M1 excitability has been reported to facilitate implicit motor learning [8,9]. In other



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words, the enhancement of dribbling and agility after atDCS on M1 may not be due to ergogenic effects but possibly due to increased automaticity via enhanced implicit motor memory [7].

The ease, cost efficiency, and high safety of tDCS make it a potentially promising adjunct modality to be used in conjunction with therapy or training settings. The safety of tDCS in terms of cognition, sensation, and perception has been well documented. Under the current safety guidelines, tDCS of the motor cortex has been reported to have relatively minor adverse effects [10,11]. However, safety reports regarding the effects of tDCS on cardiovascular autonomic function are limited, and the results are inconsistent [12]. Some studies have reported that tDCS of the motor cortex shifts autonomic function toward sympathetic output [13,14], while other studies revealed no change in blood pressure (BP) and heart rate (HR) [15,16]. tDCS is being increasingly used for performance enhancement in exercise training [2,5], and for the treatment of pathological conditions such as arterial hypertension [17]. Thus, it is important to clarify the impact of tDCS of the motor cortex on cardiovascular function and accumulate empirical evidence for the safety of tDCS.

The goal of this study is twofold. First, we investigated the effects of uni-hemispheric tDCS over dominant M1 on the indirect measurement of lower limb power. Second, we examined the ergogenic effect of tDCS over the dominant M1 on a simple agility test that minimizes implicit motor control. To achieve these goals, we first hypothesized that uni-hemispheric a-tDCS over the dominant M1, increases SLJ by modulating lower limb power. Second, the ergogenic effects seen in the complex agility test [5] will also be evident in a simple agility test that minimizes the implicit motor control. Additionally, to control the safety of tDCS administration on cardiovascular autonomic functions, HR and BP were monitored and evaluated before and after tDCS application [18].

# 2. Materials and methods

## 2.1 Subjects

Thirteen healthy collegiate students (13 males, rightleg dominance, mean age  $26.53 \pm 2.73$  years) participated in this study. Participants' heights and weights were (min/max/mean  $\pm$  SD;  $168.3/184.2/175.23 \pm 5.71$  cm) and ( $64.27/92.76/74.92 \pm 11.26$  kg), respectively. All participants were the department of sports science students of Seoul National University of Science & Technology. Participants reported being engaged in recreational sporting activities (basketball, soccer, tennis, weight training, etc.) with at least 2 hours of training a week. To determine the suitability for tDCS, all participants completed an Adult Safety Screening Questionnaire for non-invasive brain stimulation [19]. None of the participants had any contraindications for tDCS. Considering the crossover design of the present study, to determine a priori sample size (G\*Power Version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany)), the following input parameters were selected as per an F test for ANOVA-repeated measures-within factor analysis: a statistical power  $(1-\beta)$ of 0.8, a probability  $\alpha$  level of 0.05, two groups, three measurements. Effect size was set with d = 1.02 [20,21]. This effect size was calculated according to the mean and standard deviation data of a-tDCS and s-tDCS interventions [21]. As output parameters, an actual power of 0.89 and a critical F of 3.63 were obtained. Therefore, thirteen male adults were enrolled in this study. The participants were randomly assigned to the a-tDCS and s-tDCS groups. Two group randomizations were completed using a web-based program (http://www.randomizer.at/) to conceal the allocation from the participants.

## 2.2 Study design

This study was a single-blinded, sham-controlled, crossover study with a randomized block design, before the start of the experiment, using a restricted block randomization (computer-generated sequence), the participants were allocated either to a-tDCS or s-tDCS condition, and then exposed to the opposite treatment (Fig. 1). This procedure allowed us to reduce variability within the stimulation conditions and avoid greater familiarization training to tests. The allocation and randomization were completed by one of the researchers without any contact with or knowledge of the participants. Two unaffiliated experimenters conducted the experiment and collected the data. All participants were involved in two separate tDCS sessions (a-tDCS, s-tDCS) with at least 48 hours of "washout period" between the two sessions. Prior to and at the completion of each intervention session, HR and BP were monitored and evaluated, and lower limb power (standing long jump) and simple agility test (sidestep test) [22] were measured (Fig. 1). All participants were blinded to receipt of either sham or real stimulation and had a short debriefing session consisting of verbal questions after the completion of the experiment.

## 2.3 tDCS protocol

Each participant received both a single session of atDCS and a single session of s-tDCS applied over the left M1. The stimulation site was determined by the individual's dominant leg (all participants were right-dominant leg persons). Participants self-reported leg dominance in the Waterloo Footedness Questionnaire-revised (WFQ-R) [23]. To stimulate left M1, the anodal electrode was placed over 20% of the auricular measurement from Cz (according to the international 10/20 EEG system) which was placed above C3 [24]. The reference electrode was placed over the contralateral supraorbital area and the same electrode montage was used in the sham condition. For the a-tDCS condition, a constant current of 2 mA was delivered for 20 minutes, and for the sham condition, the electric current disappeared within 30 seconds. Participants received either



**Fig. 1. Schematic representation of study design.** HR, heart rate; BP, blood pressure; SLJ, standing long jump; SST, side step test; tDCS, transcranial direct current stimulation.

tDCS (HDCstim, Newronica, Italy) with an intensity of 2 mA or sham tDCS for 20 minutes on the M1 contralateral to the dominant leg between the pre-and post-physical performance measurements (Fig. 1).

#### 2.4 Measurements

HR and BP were measured before and after the tDCS application to monitor and evaluate the vital parameters. As physical abilities, standing long jump (SLJ) and sidestep test (SST) were measured for lower limb power and agility. Prior to the measurement, all participants were given enough time to warm up to prevent injury.

#### 2.4.1 Blood pressure and heart rate

Changes in systolic and diastolic BP and HR before and after the tDCS application were examined. For systolic and diastolic BP, a clinically significant change in the level of BP was set at  $\pm 10$  mmHg or more from pre- to post-tDCS administration. For HR, a clinically significant change in HR was considered when the change from pre- to post-tDCS administration was 10% or greater [18].

#### 2.4.2 Standing long jump (SLJ)

The participants performed an SLJ to assess the lower limb power. It was performed on a non-slip rubber floor with a foul line and three successful attempts, with 2 minutes breaks in between were recorded. Prior to the actual test, participants were allowed two training attempts at a submaximal intensity to familiarize themselves with the test. The mean of the successful attempts was used in the analysis. The distance of the jump was quantified using a mobile phone (iPhone 6 plus; Apple, Cupertino, CA, USA) at a sampling frequency of 240 Hz using the My Jump app [25]. The App was scientifically validated [26] and measures the distance of the SLJ by identifying the participant's height, and the take-off and landing frames of the video.

#### 2.4.3 Sidestep test (SST)

Agility was assessed using the SST (Fig. 2). A centerline was drawn on the ground at the start of the test. An additional line on each side of the centerline which was 100 cm away from the centerline, was drawn using a measuring tape. With the starting signal, the participant sidestepped to the right until his foot had reached or touched the outside line to the right and returned to the centerline. The participant then sidestepped to the left until his left foot touched or crossed the outside line to the left. The participant repeated these movements as quickly as possible for 10 seconds. One-foot tick mark was placed between the centerline and the outside line, each movement from centerline across marker counts as follows: moving across right crosses tick (1), outside line to the right (2), then back tick (3), centerline (4), across the left tick (5), outside line to the left (6), back tick (7), and centerline (8). One complete cycle yielded a score of eight points. A total score within ten seconds was taken [27].

#### 2.4.4 Calculation of tDCS induced current flow

The tDCS induced current density, electric field, and electric potential regarding the electrode montage arrangement were created using COMETS2 that a MATLAB toolbox for the numerical analysis of the electrical field generated by tDCS [28]. A realistic human head model consisting scalp, skull, cerebrospinal fluid, and white and grey matter is adopted as a default head model. Anode and cathode dimensions and placement were best approximated to capture



Fig. 2. Schematic representation of lines and tick marks for the side step test.

the features of the electrode montage.

Numerical calculations of the tDCS induced current flow (0.201 V/m), current density (0.150 mA/cm<sup>2</sup>), and electric potential (0.016 V) were estimated and heightened at Montreal Neurological Institute (MNI) coordinates (x = -36, y = -24, z = 66) for the left M1 in the human motor area template [29,30]. Fig. 3 shows the current density profile (a), brain electric field intensity (b), and electric potential (c) for the tDCS montage used in this study, and illustrates restricted stimulation with a peak directly underneath the anode and current restricted within the boundary of the reference electrode. An obvious electric potential increase was observed within a major part of the dominant M1, while a prominent decrease was detected in the non-dominant prefrontal cortex.

#### 2.5 Statistical analysis

The normality of the collected data was checked using both the Shapiro-Wilk test and Kolmogorov Smirnov test and found to be normally distributed (all p > 0.05); thus, parametric analyses were utilized for data analysis. A repeated-measures analysis of variance (ANOVA) with factors "condition" (a-tDCS and sham tDCS) and "session" (pre and post) were applied to evaluate the 2 mA tDCS on vital parameters, SLJ, and SST. A partial eta squared  $(\eta_p^2)$ was calculated as the effect size, and the level of significance was set at  $p \le 0.05$ . The test-retest reliability of the SLJ and SST was measured using intraclass correlation coefficient (ICC, Cronbach- $\alpha$ ) and interpreted as follows:  $\alpha$  $\ge 0.9 =$  excellent;  $0.9 > \alpha \ge 0.8 =$  good;  $0.8 > \alpha \ge 0.7 =$ acceptable;  $0.7 > \alpha \ge 0.6 =$  questionable;  $0.6 > \alpha \ge 0.5 =$ poor [31].

# 3. Results

For SLJ, the ANOVAs revealed that the main effect of stimulation conditions ( $F_{(1,24)} = 0.02$ , p = 0.86,  $\eta_p^2 = 0.001$ ), test sessions ( $F_{(1,24)} = 1.18$ , p = 0.28,  $\eta_p^2 = 0.047$ ), and the interaction between condition and session ( $F_{(1,24)} = 0.40$ , p = 0.53,  $\eta_p^2 = 0.017$ ) were not significant (Fig. 4a). The reliability of the SLJ was excellent ( $\alpha = 0.940$ ). In addition, ANOVAs include SST score as a dependent measure showed that the main effect of stimulation conditions ( $F_{(1,24)} = 0.57$ , p = 0.45,  $\eta_p^2 = 0.024$ ), test sessions ( $F_{(1,24)} = 0.12$ , p = 0.73,  $\eta_p^2 = 0.005$ ), and the interaction between condition and session ( $F_{(1,24)} = 0.58$ , p = 0.45,  $\eta_p^2 = 0.024$ ) were not significant (Fig. 4b). The reliability of the SST was acceptable ( $\alpha = 0.761$ ).

ANOVAs, including HR data, revealed that the main effect of stimulation conditions (F<sub>(1,24)</sub> = 0.02, p = 0.87,  $\eta_p^2$ = 0.001), test sessions (F<sub>(1,24)</sub> = 1.2, p = 0.27,  $\eta_p^2 = 0.05$ ), and the interaction between condition and session ( $F_{(1,24)}$ ) = 1.41, p = 0.24,  $\eta_p^2 = 0.05$ ) were not significant (Fig. 4c). Regarding the BP data, the ANOVAs showed that the main effect of stimulation conditions ( $F_{(1,24)} = 1.62$ , p = 0.21,  $\eta_p^2 = 0.063$ ), test sessions (F<sub>(1,24)</sub> = 0.11, p = 0.73,  $\eta_p^2 = 0.005$ ), and the interaction between condition and session  $(F_{(1,24)} = 0.63, p = 0.44, \eta_p^2 = 0.026)$  were not significant (Fig. 4d). More specifically, six participants showed a clinically significant change in systolic BP ranging from -20 to +15 mmHg (Table 1). The participants showed bidirectional changes regardless of the tDCS polarity. One participant showed increased systolic BP, while the other participant showed decreased systolic BP after a-tDCS. Under the sham condition, four participants showed a clinically significant increase in systolic BP, while one participant showed a decrease. In terms of diastolic BP, three participants showed a clinically significant decrease only in the sham condition while one participant showed a clinically significant decrease in HR after a-tDCS.





Fig. 3. 3D map of tDCS current flow using COMAT2. Simulation of (a) current density, (b) electric field intensity, and (c) electric potential induced by 2 mA tDCS with the anode ( $5 \times 7$  cm) over the left M1 (C3) and the reference electrode ( $5 \times 7$  cm) over the right supraorbital area (Fp3). Green dots denote the international 10–20 system of electrode placement. Coronal, right, left, and superior view of the brain are presented (from left to right).

Table 1.	Changes	in	BP	and	HR.
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	Subject #4		Subject #5		Subject #6		Subject #7		Subject #8		Subject #9	
	condition	value										
$\Delta$ systolic BP (mmHg)	А	+13	-	-	-	-	-	-	-	-	А	-20
	S	+15	S	+16	S	-11	S	+11	S	+12	-	-
$\Delta$ diastolic BP (mmHg)	-	-	-	-	-	-	-	-	-	-	-	-
	S	-13			S	-18	S	-9	-	-	-	-
$\Delta$ HR (%)	-	-	-	-	-	-	-	-	-	-	А	16.66
	-	-	-	-	-	-	-	-	-	-	-	-

Clinically significant change from pre- to post-tDCS application ( $\Delta = \text{post-pre}$ ) in systolic and diastolic BP and HR. Positive values denote increase and negative values indicate a decrease.

## 4. Discussion

The aim of this study was to determine whether a single session of anodal 2 mA tDCS applied over the dominant M1 led to increased physical ability in terms of agility and lower limb extensor power. This study based on the idea that increased recruitment was assumed to occur through atDCS used to facilitate M1 activity and that enhanced M1 excitability has positive effects on physical performance. Several tDCS studies have provided empirical evidence of the positive effects of a-tDCS on both direct [24,32,33] and indirect [5,34] measurements of physical ability. However, in this study, the application of a single session of 2 mA anodal tDCS for 20 minutes over the dominant M1 was not able to establish a short-term improvement in SLJ and SST.

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According to SLJ results in this study, lower limb muscle power did not change after 20 minutes of a-tDCS over the dominant M1. This result is not consistent with the work of Lattari *et al.* [2]. The main difference between the two studies is the electrode montage. Lattari *et al.* [2] stimulated M1 bilaterally, whereas in the present study, the dominant M1 was targeted. Both direct measurement [6,35] and indirect measurement [2] unanimously reported increased muscle strength and performance enhancement. Specifically, the direct measurement studies considered the lateralization effect of the stimulated hemisphere, hence, the authors focused on the performance of the dominant limb (contralateral to stimulated M1). In contrast, an indirect measurement study using bi-hemispheric a-tDCS



**Fig. 4. Physical performance, heart rate, and blood pressure measures.** Changes in physical performance, HR, and BP measures from pre-tDCS session to post-tDCS session in the (a) standing long jump, (b) sidestep test, (c) heart rate, and (d) blood pressure. Error bar represents standard error.

of the M1 revealed enhancement of the lower limb muscle power of an individual with experienced weight training. Another indirect measurement study investigating the frequency speed of kick test of Taekwondo athletes showed that bilateral a-tDCS worsened the physical performance even though the stimulation intensity and duration were weaker and shorter (1.5 mA and 15 minutes) [36]. Combining the previous studies and the results of this study, our findings suggest that bi-hemispheric stimulation would have a more positive effect on indirect measurement of physical performance, such as CMJ or SLJ, which require the use of both limbs, compared to unilateral stimulation.

A previous indirect measurement study showed that 20 minutes of 2 mV a-tDCS over dominant M1 enhanced the performance of the complex dribbling agility test [5]. However, in the present study using the same stimulation intensity, duration, and montage, the ergogenic benefit of a-tDCS was not observed in SST. The inconsistent results of this study may be due to the nature of the experimental tasks. Veldema *et al.* [5] asserted that a task com-

posed of the complex sequences and required vigorous use of the dominant hand led to increased neural activity of the contralateral hemisphere and its inhibitory influence on the ipsilateral brain area. However, the task of this experiment, that minimizes the dexterity of the dominant hand and automatized implicit motor control, simply required fast lower-limb movement. The tDCS montage in this study was modeled using the toolbox COMETS2 [28]. As confirmed in Fig. 3 of this study as well as in the Veldema et al.'s [5] study, the induced current flow exhibits facilitatory changes within the dominant M1 area where the active electrode is located. In contrast, inhibitory changes were observed within the non-dominant prefrontal area as well as within the bilateral orbitofrontal areas. The interhemispheric inhibition, which depicts reciprocally interacting inhibitory processes exerted by both hemispheres toward one another via the corpus callosum, explains this activation pattern [37]. A vigorous hand movement increases cerebral activity in the contralateral hemisphere and has an inhibitory effect on reciprocal brain areas [38]. In other

words, a decrease in transcallosal inhibition from the dominant to nondominant hemisphere was linked to improved motor function in the nondominant hand [39]. This raises the possibility that increased neural excitability of dominant M1 and decreased neural processing within non-dominant prefrontal areas may have contributed to the improvement in implicit motor control and hand dexterity associated with the complex dribbling agility test [5,8] rather than the ergogenic benefits. This implies that uni-hemispheric a-tDCS may not be a valuable tool to produce physical performance enhancement from a simple agility test requiring only ballistic movements of both lower limbs. It also suggests that the uni-hemispheric stimulation is not sufficient to obtain the ergogenic benefits from tasks that require bilateral lower limb strength [6,24].

In terms of the safety of tDCS application, the results of the present study support empirical evidence that tDCS treatment is free from serious adverse events. While a few participants reported unpleasant tingling and prickling sensations under the electrode during the tDCS session, these non-SAEs were minor and disappeared within a minute. Monitoring and evaluation of systolic and diastolic BP and HR before and after the tDCS session revealed bi-directional changes in the vital parameters regardless of the tDCS polarity. This finding is consistent with a previous study [18] that suggests changes in BP and HR were not specific to participants with a history and/or current status of hypertension. A recent review of non-invasive brain stimulation effects on the autonomic nervous system suggested that focal modulation of cortical excitability by tDCS can influence sympathetic outflow and BP as a tool in the therapeutics of human hypertension [17]. However, our finding of occasional bi-directional fluctuation, did not confirm the decreasing effect of tDCS on BP. This implies that careful attention is required, such as monitoring the online changes in BP and HR throughout the tDCS application period; thus, further research on the effect of tDCS on BP is warranted.

In addition, it is important to note the existence of a publication bias, encouraging positive results. Studies that found no changes after treatment or with findings that are opposite to the expected results are less likely to be published [40]. Setting aside the possibility of wasting other researchers' time and effort, not reporting negative results brings down the validity of meta-analysis and the ability to draw conclusions about a specific treatment [41].

In the end, this study has some limitations. First, devices such as electroencephalography or electromyography were not used to assess or monitor brain responses (supraspinal or peripheral) during post-stimulation. As a result, the data obtained do not allow us to make any definitive statements on the physiological pathways through which tDCS may act. Future research could focus on determining the primary involvement of neurological variables, whether supraspinal or peripheral. Second, we cannot rule out the possibility that the current stimulation affected the M1 adjacent areas. A neuroimaging study combined with tDCS and fMRI found that other areas were also stimulated [42]. Third, while a priory modeling of the resultant current flow at M1 was conducted (see Fig. 3a–c), it is important to note that this does not take into account that the actual current flow was likely influenced by the parameters and electrode arrangement used for stimulation. Forth, to find routines and methods to gain neuromuscular benefits for physical performance, further research is necessary to apply alternative tDCS protocols with different electrode montages and electrode sizes, or high-definition tDCS to stimulate the accurate motor cortex and target muscle. In addition, longterm effects and repetitive tDCS sessions should be tested with a larger sample size to develop a unified stimulation protocol for optimal outcomes.

## 5. Conclusions

The present findings are inconsistent with the idea that increased recruitment of M1 using a-tDCS application plays a critical role in the acute improvement of physical activity. Uni-hemispheric a-tDCS was insufficient to improve ballistic actions such as SLJ or SST in this experimental population. These findings suggest that the stimulation protocol and electrode montage would not be effective in improving lower limb muscle strength or agility. Although most of the available data indicate a positive effect of tDCS on the direct measurement of physical ability, it has not been confirmed in the experimental setting and tasks of this study. Hence, the findings of this study suggest that tDCS applied over the M1 for 20 minutes may not be a valuable tool to enhance lower limb power output in exercises such as SLJ and SST.

## **Author contributions**

IP and SKK—Conceptualization; IP—Methodology; IP, YK, and SKK—Validation; IP—Formal Analysis; IP and YK—Investigation; IP and YK—Data Curation; IP— Writing-Original Draft Preparation; IP and SKK—Writing-Review and Editing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

## Ethics approval and consent to participate

All subjects gave their informed consent for inclusion before they participated in the study, which was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the Institutional Review Board at Korea Institute of Sport Science (KISS-1909-021-02).

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# **Conflict of interest**

The authors declare no conflict of interest.

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