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The Optimal Stepping-in-place Tempo and Type of Roundhouse Kick for the Strong Impact Force in Taekwondo

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Abstract

The aims of this study were to investigate the effects of stepping-in-place tempo on impact force of round house kick and to determine whether the impact force was the same according to types of round house kick; front leg body; front leg head; rear leg body; rear leg head. Fifteen Taekwondo experts performed four type of roundhouse kicks at five different stepping-in-place tempos; 100; 120; 140; 160; 180 bpm. Each participant performed 60 round house kicks body and head height in random order. The impact force was analysed using 4 (kick type) × 5 (tempo) ways repeated measures ANOVA. Estimated impact force at 140 bpm was significantly stronger than at 100 bpm. Estimated impact force for FLB and RLB were stronger than FLH and RLB was stronger than RLH. In addition, kick type x tempo interaction was significant. The findings of this study indicate that there exists an ideal stepping-in-place tempo for generating robust impact force, and that body kicks consistently yield more impact force in comparison to head kicks across all stepping-in-place tempos. This study provides useful information on the optimal movements for enhancing Taekwondo performance related to power output and has important applications for both coaches and players establishing Taekwondo match strategies.

Key words: Taekwondo, impact force, stepping-in-place tempo, roundhouse kick

Introduction

Taekwondo is one of the most popular martial arts and combat sports, spectators fascinated by its powerful attacks and highly trained techniques. Participation in combat sports necessitates the development of exceptional levels of technical expertise, strategic insight, and physical conditioning (Ouergui et al., 2015). Unlike other sports disciplines, such as track and field or ball games, distance between the opponent, fast reaction time and impact force are the factors that ensure the successful strategy and winning game (Ervilha et al., 2020; Górski & Orysiak, 2019).

In combat sports like boxing, strikes are limited to the upper limbs, but other disciplines like Taekwondo (TKD), karate (KA), kickboxing (KB), Muay Thai (MT), and mixed martial arts (MMAs) permit the use of both upper and lower limbs. In Taekwondo, kicks are the most commonly used striking technique (Kazemi et al., 2010), while in Karate, punches are delivered more frequently than kicks (Ibáñez et al., 2018). Although the frequency of kicks may be lower in Karate, delivering high-impact force and velocity of kicks remain a critical tactical element and a crucial determinant of success in competition (Falco et al., 2009; Górski & Orysiak, 2019).

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Across disciplines, numerous kicking techniques are utilized, comprising roundhouse, front, back, side, and axe kicks (Ambroży et al., 2020; Kwok, 2012). In the context of TKD, the roundhouse kick is regarded as the most frequently employed technique (Bercades et al., 2023) and has been reported as the primary means of knockout or number of points scored (Falco et al., 2013). Numerous studies have examined different aspects of kicking performance, encompassing the various kinematic stages of kicking (Lin et al., 2023; Moreira et al., 2021), interdisciplinary comparisons of performance (Diniz et al., 2021), the influence of training interventions, and the physical factors that contribute to kicking performance (Moreira et al., 2015). Especially, various investigations have explored regarding impact force. Related studies suggested the mechanisms that optimal use of proximal-to-distal motion (Falco et al., 2009), effective application of body mass (Ramakrishnan et al., 2018), and increased muscular activation (Moreira et al., 2018). In addition, lower body and hip strength can impact kicking performance (Moreira et al., 2015; Vagner et al., 2019), stepping-in-place tempo (Lee & Song, 2019) and flexibility (Ng & Jumadi, 2022) all being identified as key factor that influence kicking performance.

Fitt's law, commonly known as the speed accuracy trade-off, was evident in studies related to the change in kicking impact and velocity depending on that both the distance from and size of the target. A smaller target size typically leads to a decrease in kicking velocity, a modification that is likely made to fulfil increased accuracy demands (Wąsik & Góra, 2016; Wąsik et al., 2021a; Wąsik et al., 2021b). In other words, head kick generally produce lower impact force and velocity compared to those targeting the trunk (O'Sullivan et al., 2008; O'Sullivan et al., 2009), as the need for precise targeting necessitates a reduction in absolute velocity. Studies primarily investigating impact force have generally proposed that a greater distance from a target provides more time for the striking limb to accelerate before to impact, hence potentially enhancing the impact force (Górski & Orysiak, 2019). However, interaction between impact force and target distance can be more complex depending on the skill level, weight classes and accessing methodologies. Although different methodologies used in the studies may account for conflicting results, if exogenous variables such as skill level or weight classes are limited, it is sufficient to determine the effect of initiation of actions such as stepping-in-place. Thus, in this study, the skill level and weight class limited to the elite athletes and 60kg weight classes (feather and light classes), and investigated which type of round house kick and stepping-in-place tempo can produce the strong impact force.

The aim of this study was to examine whether stepping-in-place tempo affects the impact force of roundhouse kick as an initiation actions and define the optimal tempo for the strong roundhouse kick. We hypothesis that:

1) There are significant differences in impact force of roundhouse kick according to each stepping-in-place tempo (very slow, slow, medium, fast and very fast tempo).
2) There are significant differences in impact force at each stepping-in-place tempo relative to the type of kicks (i.e. front, rear, body, and head).

Methods

Participants

15 Taekwondo experts (age: 19.20 ± 0.94 years, height: 173 ± 5.32 cm, weight: 65.60 ± 4.49 kg, experience: 11.53 ± 2.15 years) participated in this study. All subjects were currently enrolled athletes in Korea Taekwondo Association (KTA) and fourth- degree black belts and right-foot dominants. All participants informed about the objective of the study, experimental task and procedures prior to the onset of the experiment and signed an informed consent form approved by the Seoul National University Institutional Review Board (IRB No. 1809/001-012) after volunteering to participate.

Task and Apparatus

The task of this study is performing a different type of roundhouse kick at the right time by synchronizing

the stepping-in-place to the given metronome tempo. Prior to the data collection, to set the stepping-in-place tempo for the experiment, an individual's preferred stepping-in-place tempo was measured. The participants were asked to perform stepping-in-place synchronized to the tempo of the metronome. There were five different metronome tempos that pre-defined as a very slow (100 bpm; beat per minute), slow (120 bpm), medium (140 bpm), fast (160 bpm), and very fast (180 bpm). Stepping-in-place according to the given metronome tempo and then kicking the punching bag as hard as possible at the light signal (the punching bag has an inbuilt accelerometer to measure the impact force). The types of roundhouse kick are classified according to the location of the kicking leg and the target area: front leg-body (FLB), front leg-head (FLH), rear leg-body (RLB), and rear leg-head (RLH). Each participant performed a total of 60 repetitions consisted of three kicks according to the four different types of roundhouse kicks at five tempos. The experimental set-up is shown in Figure 1.

To measure an impact force, punching bag with an embedded accelerometer was developed based on the O'Sullivan study (2009). Typically, impact force is measured by installing a ground reaction force device on a stationary surface. However, participants would not be able to exert their maximum strength because there is a risk of injury when directly kicking the ground reaction force device. Also, if the ground reaction force device is vertically erected, the value would be different from when measured by installing it on the ground. Therefore, punching bag with an embedded accelerometer was developed to indirect measurement of kicking strike force.

To calibrate the accelerometer, punching bag dropped 50 times from varying heights onto the strain gauge type ground reaction force platform (AMTI OR6-7, USA). The acceleration outputs from the accelerometer and the force platform was recorded at 1000 Hz and compared. Pearson's correlation coefficient (r = .99) was obtained and declared satisfactory (Figure 2). According to relevant studies, r =.91 (O'Sullivan et al., 2009) and r = .99 (Sidthilaw, 1997). The kicking impact force was calculated by entering the accelerometer's acceleration value into Equation (1) below.

$$\text{Estimated Force (N)} = 2.764(\text{accelerometer's value}) + 374.195 \quad (1)$$

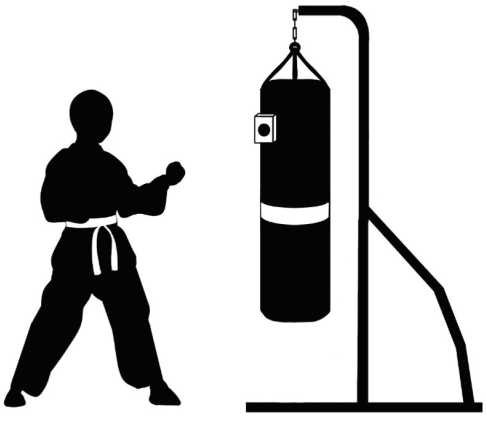

Figure 1. A schematic visualization of the experimental set-up. The participants performing the stepping-in-place according to the given metronome tempo and assuming the ready position for the roundhouse kick to measure impact force.

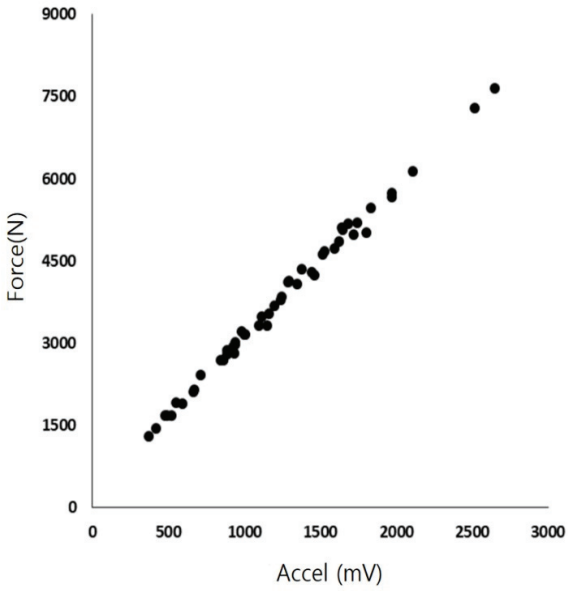

Figure 2. Plot of calibration data for accelerometer embedded punching bag.

Procedure

Before beginning the experiment, all participants were given adequate time to warm up and practice the experimental task, while the distance and height of the apparatus were adjusted based on each participant's physical attributes. Because all participants were right-footed, the kicking performance was carried out in left sparring posture (a prepared stance with the left leg front). Following the warm-up, each participant had three attempts at the light signal to acquaint himself with the test protocol. All subjects took part in four separate experiment sessions, each with a "recovery period" of at least 4-5 days. Each testing session included four different types of roundhouse kicks assigned at random. Participants were briefed about the type of roundhouse kick at the start of the session, and they chose a stepping-in-place tempo at random, which was repeated three times each. As a consequence, participants completed a total of 60 roundhouse kicks over the experiment sessions (15 kicks per session). Participants were given 30 seconds' rest after each attempt, followed by a three-minute break after the ninth.

Statistics

The raw scores for each participant across each kick type and stepping-in-place tempo were summarised to generate estimated force scores, which were used as the dependent variables. To compare the effect of stepping-in-place tempo on impact force, a 4 (kick type) x 5 (tempo) ways repeated measures analysis of variance (ANOVA) was conducted. Significant factor effects and interactions were subsequently examined using the Bonferroni adjustment for multiple comparisons and Pearson's ratio for detection of effect sizes (classified $r < 0.3$ small, $r = 0.3$-0.5 moderate, and $r > 0.5$ large effect size). All statistical analyses were performed using SPSS version 27 (Chicago, IL, USA) with a statistical significance level of $p < .05$.

Results

A day before the actual experiment, the mean stepping-in-place tempo was checked and used above and below the mean frequency (of 20 and 40 bpm) as a required tempo in this experiment. The mean and standard deviation (SD) of participant's individual steps of stepping-in-place performed during the 10s period was 23.60±1.59 times, which was 141.60±9.56 bpm (min/max: 126/156 bpm) when converted to bpm. Accordingly, the stepping-in-place tempos used in this study were set to 100 (very slow), 120 (slow), 140 (medium), 160 (fast) and 180 (very fast).

Mean [95% CI] of estimated impact force from four different type of kicks (FLB, FLH, RLB, and RLH) in stepping-in-place tempo at 120 bpm, 140 bpm, and 160 bpm are presented in Table 1.

Using a 4 (kick type) × 5 (tempo) ways repeated

Table 1. Mean [95% CI] of estimated force from four different type of kicks (front leg body, front leg head, rear leg body, and rear leg head) in stepping-in-place tempo at 100, 120, 140, 160 and 180 bpm

		FLB	FLH	RLB	RLH
Estimated force (N)	100 bpm	3744.33 [3136.59; 4352.08]	2851.48 [2243.74; 3459.23]	3776.28 [3168.53; 4384.02]	3640.70 [3032.96; 4248.45]
	120 bpm	4373.94 [3670.13; 5077.45]	2884.55 [2181.04; 3588.06]	4517.69 [3814.18; 5221.20]	3223.25 [2519.74; 3926.76]
	140 bpm	4125.17 [3438.93; 4811.40]	2962.61 [2276.39; 3648.87]	5355.01 [4668.77; 6041.25]	3840.77 [3154.53; 4527.01]
	160 bpm	4916.49 [4406.11; 5426.88]	2517.28 [2006.90; 3027.67]	4267.87 [3757.48; 4778.25]	3279.98 [2769.59; 3790.36]
	180 bpm	4747.67 [3939.85; 5555.49]	2768.96 [1961.14; 3576.79]	4482.57 [3674.75; 5290.39]	3591.59 [2783.76; 4399.41]

Table 2. Results of 4 (kick type) x 5 (tempo) ways repeated measures ANOVA/ Post-Hoc analysis of the interactions. Estimated force for Type × Tempo interaction

Estimated force, Type Tempo interaction				
Tempo (bpm)	Type	Post hoc	P value	Effect size (*r*)
100 120 140 160 180	FLB RLB FLH RLH	No significant interactions were find		
Type	Tempo (bpm)	Post hoc	P value	Effect size (*r*)
FLB RLB FLH RLH	120	FLBFLH*	< .05	.148
		FLHRLB*	< .05	-.076
		FLHRLB*	<.001	.123
		RLBRLH*	< .05	.572
	160	FLBFLH*	<.001	-.188
		FLBRLH*	<.001	-.058
		FLHRLB*	<.001	-.023
		RLBRLH*	< .05	-.042
	180	FLBFLH*	< .05	.213
		FLHRLB*	< .05	-.265

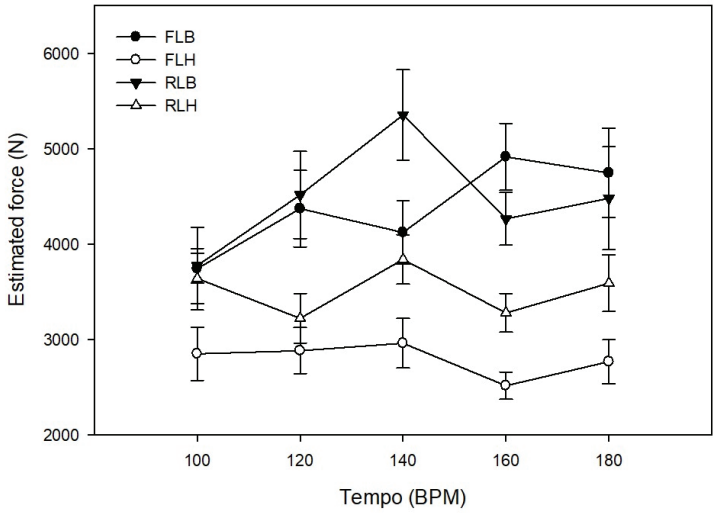

Figure 3. Mean ± SE of estimated impact force for each kick types (solid dot: FLB, open dot: FLH, solid triangle: RLB, and open triangle: RLH) as a function of stepping-in-place tempo. Error bars represent the standard error.

measures ANOVA, results revealed a significant main effects of kick type ($F(3, 56) = 10.30$, $p < .001$, η_p^2 = .356), and stepping-in-place tempo (F (4, 224) = 2.76, p =.028, η_p^2 = .047). Estimated impact force scores for FLB and RLB were stronger than FLH (*ps* < .001, *rs* = .086, -.034), RLB was stronger than RLH (p =.047, r > .188), and there were no differences between FLB, FLH and RLH. Estimated impact force at 140 bpm was significantly stronger than 100 bpm (p = .025, r = .448), and there were no differences between other stepping-in-place tempos. In addition, kick type x tempo (F (12, 224) = 2.46, p = .005, η_p^2 = .116) interaction was significant. For further detail (post-hoc analysis and effect size) of the interaction, see Table 2.

Discussion

The purpose of this study was to explore the effects of different stepping-in-place tempos and performance of four different types of roundhouse kicks on the impact force in a sample of Taekwondo experts. The analysis of the impact force data showed a significant difference between stepping-in-place tempos, as well as the types of roundhouse kicks. Overall, the results of this study found that there are significant differences in impact force according to the stepping-in-place tempo. Hypothesis 1can therefore be accepted in terms of the analysis of impact force, the scores were significantly higher at medium tempo (140 bpm) compared to the very slow tempo (100 bpm). A previous study regarding the striking force with or without the stepping-in-place on the roundhouse kick in Taekwondo reported that higher striking force was shown in body roundhouse kick with stepping-in-place as compared with non-stepping-in place condition (Lee & Song, 2019). However, another study analyzed the ground reaction force reported the opposite result that the roundhouse kick without stepping-in-place was more powerful than the other one (Park, 2014). In this study, a higher impact force of the roundhouse kick was shown in preferred stepping-in-place tempo (140 bpm) rather than the slow (100 and 120 bpm) or fast (160 and 180 bpm) tempo. This result implies that preferred stepping-in-place tempo plays a role as an initiation action such as Stretch-Shortening Cycle (SSC). In addition, stepping-in-place as an initiation action allows a fighter to utilize inertial force more effectively because it generates higher kinetic energy at the moment of detecting external stimulus (Kim & Kim, 2014; Lee & Song, 2019).

In terms of comparing the target location (body vs. head), participants in this study showed a higher impact force on the body kick than the head kick across the all stepping-in-place tempo (see Figure 2). Typically kicking impact and velocity are directly linked to the distance from and size of the target. Specifically, the tendency of head kick to elicit lower impact force and velocity in comparison to body kick (O'Sullivan et al., 2008; O'Sullivan et al., 2009) because accurate targeting requires a decrease in absolute velocity. This notion was confirmed at 120, 160, and 180 bpm for the front kicks (rs = -0.18 - 0.21), and at 140 and 160 bpm for the rear kicks (rs = -0.04 and 0.57) in this study. From the perspective of the kicking leg, a higher impact force was measured in RLB than FLH at all stepping-in-place tempo except 100 bpm, thereby the impact force decreases for accuracy, and at the same time, the impact force for the body kicks that do not require accuracy can increase as the distance from the target increases with the rear leg. This results indicate that a greater distance from a target gives the striking limb more time to accelerate before the impact, potentially increasing impact force (Górski & Orysiak, 2019). Therefore, hypothesis 2 is accepted in terms of the identified significant difference in impact force of each stepping-in-place tempo relative to the type of kicks (i.e. front, rear, body, and head). Numerous studies accessing distance from a target demonstrated that the increased summation of body segment rotation by altering the stance angle by 45-90 degree to the target produced higher kicking velocity and impact force, an effect that is more potent at larger angles of attack (Estevan et al., 2013; Jandačka et al., 2013; Jung & Park, 2022). Although the stance angle was fixed in this study, it was confirmed that the striking limb was placed further away from the target and had a greater effect on the rear leg than the front leg, where acceleration could be used more effectively.

Recent studies examined the various performance outcome regarding the roundhouse kick in Taekwondo reported consistent results that stepping-in-place provides positive effect in performance. For example, a study analyzing the ground-reaction force during roundhouse kick with stepping-in-place showed that ground reaction force toward attack direction have reduced the required movement time by increasing the speed of hip joint movement (Kang, 2017). In addition, a study investigates the response time of roundhouse kick with five different stepping-in-place tempo that the same experimental set-up as this study, found the fastest response time were measured at 140 bpm (Lee

& Song, 2019). The study emphasized that 140 bpm was the most preferred tempo by participant's and the situation make a fighter stable and comfortable ensure the optimal performance. Another study analyzed the Coincidence Anticipation Timing (CAT) performance of round house kick during a different stepping-in-place tempo found that the most accurate and consistent CAT performance were identified at participant's preferred tempo (140 bpm) (Lee & Park, 2022). In sum, the use of appropriate stepping-in-place tempo for a round-house kick can be an all-round movement that allows fighters to predict the opponent's movements, create a quick reaction, and provide an opportunity to attack with powerful impact force.

This study revealed that the tempo of stepping-in-place, a preparatory movement for an attacking kick in Taekwondo, had a significant impact on the force of the roundhouse kick. Specifically, the study found that experts achieved the highest impact force when performing the stepping-in-place at 140 bpm. Notably, this tempo closed aligned with the average stepping frequency observed among the study participants. Multiple experiments combining stepping-in-place with secondary tasks to study attentional demands have revealed that excessively slow or fast stepping-in-place tempos are differentially controlled compared to preferred tempos (Ikeda et al., 2014; Toyama & Fujiwara, 1990). These findings suggest that maintaining non-preferred stepping rates requires more cognitive resources and conscious control. Specifically, when participants were asked to perform significantly slow or fast stepping-in-place tempo than their preferred pace, the demonstrated increased difficulty in maintaining consistent performance, especially when attention was divided by a secondary task. This contrasts with performance at preferred tempos, which appeared to be more automatic and less demanding of attentional resources. These results highlight the importance of considering individual preferences and natural rhythms in movement tasks, as they may influence cognitive load and overall performance in complex motor activities like those found in Taekwondo training and competition.

Limitations

Despite the findings presented in this study, there are some limitations. For accurate comparison of the impact force, skill level and weight class that can directly affect to the output were limited. Since weight class has a direct effect on impact force, it is recommended that follow-up studies compare the differences in impact force across weight classes. Nevertheless, methodological conflicts still remain. These conflicts include variabilities or mistakes in sensor positioning (Straiotto et al., 2021), abnormal motions of kinematic makers (Preuschl et al., 2016), and variances in protective gears used on devices to absorb impact force (Vágner et al., 2018). In particular, the lack of a universally accepted 'gold standard' for impact force offers a significant difficulty to the standardization of striking performance. Additionally, the optimal stepping-in-place tempo may differ from very low or high weight classes; as a result, measurements should be taken at a variety of tempos according to the athlete's physical state.

Implications

Various jumping movements, such as drop jumps or countermovement jumps, should be incorporated into training programs as initiation action for explosive and ballistic movements. It is crucial to determine the optimal stepping or jumping conditions to enhance performance (Bobbert et al., 1987b; Bobbert et al., 1996). While this study focused solely on roundhouse kick power output, it is important to note that Taekwondo matches involve open-motor skills. Therefore, it is essential to consider both temporal and spatial factors in relation to an opponent's movements during training and competitions.

The results of this study suggest that coaches and trainers should emphasize the use of specific stepping-in-place tempos during training and competition to achieve optimal results for sport-spcific skills. However, more comprehensive approach is needed to fully understand the dynamics of Taekwondo performance.

Conclusions

This study conducted a comparative analysis of impact force according to stepping-in-place tempo, and type of roundhouse kick. The conclusions are as follows. First, according to the stepping-in-place tempo, there was a significant difference in the impact force of roundhouse kick. Second, significant differences according to stepping-in-place tempo were also evident between the front leg kick and rear leg kick, and the same results were observed between body kick and head kick. Based on these findings, it was determined that stepping-in-place tempo and type of roundhouse kick influence the impact force of roundhouse kick. This study provides useful information on the optimal movements for enhancing Taekwondo performance related to power output and has important applications for both coaches and players establishing Taekwondo match strategies.

Author Contributions

Conceptualization: I.P, J.L
Data curation: J.L
Formal analysis: I.P, J.L
Investigation: J.L
Project administration: J.L
Writing-original draft preparation:I.P, JL
Writing-review and editing: I.P

Conflict of Interest

The authors declare no conflict of interest.

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