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Relationship of kinetic and somatic variables to kicking strength in female taekwon-do athletes

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Abstract

Purpose

The objective of this study is to ascertain how specific somatic traits and kinematic indices influence the force of a punch, contingent on the type of kick (i.e. turning kick and side kick).

Methods

One hundred kicks were performed by five female elite ITF taekwon-do (International Taekwon-do Federation) athletes (aged 27.0 ± 4.8 years, body mass 64.2 ± 5.8 kg, height 163.0 ± 6.5 cm). To record the force of the impact, a strain gauge platform padded with a training disc was used as a target to protect the participants from direct impact on a force plate mounted on a stable structure.

Results

The study demonstrated that the side kicks of female taekwon-do athletes achieved, on average, a higher peak pressure force (1770 N) than the turning kick (1379 N) ($p < 0.01$). Conversely, the lower limb segments demonstrate an inverse trend in terms of average peak acceleration values. The effective mass values recorded in this study expressed as a percentage of the athletes' total body mass, were approximately 18% for the turning kick and 85% for the side kick.

Conclusions

The findings of these studies demonstrate that pressure force evidently increases with rising effective mass. However, no correlation was observed between the acceleration of the foot and the other segments of the lower limb. The calculated β^* factor indicates that there are no lateralisation differences in pressure force between kicks performed with the right and left leg.

Keywords: Athletic Performance, Motor Skills, Taekwon-do, Biomechanics of martial arts

Intoduction

The biomechanics of kicks in female martial arts practitioners involves a complex interaction of kinetic factors. Understanding these elements can potentially improve training methods and athletic performance while reducing the risk of injury [17]. Consequently, there is an ongoing need for research into the specific needs and characteristics of women martial arts trainers in different disciplines. It is well known that the biomechanics of sports techniques differ between the sexes [10]. Men generally generate higher velocities and exhibit different joint angles compared to women. Conversely, female athletes tend to utilise a broader range of trunk flexion, which impacts the biomechanics of the side kick. These differences underscore the necessity to adapt coaching strategies to enhance kick performance in women [4].

Preliminary studies have indicated that experienced female martial arts athletes generate greater values of kinematic variables, which translates into more powerful kicks [7]. Effective kicks are characterised by rapid knee extension and high hip flexion velocity, which play a key role in generating striking power in various martial arts [8, 25]. The power of kicks is influenced by more than just muscle strength; the ability to execute an effective movement pattern and coordination is also important. Experienced athletes have been shown to exhibit superior muscle recruitment, thereby augmenting the potency of their kicks [18]. Research suggests that electrical stimulation can improve specific sports movements, such as the turning kick, by reducing reaction time and execution, although it does not increase maximal strength capabilities. This finding underscores the significance of enhancing neuromuscular performance for optimising kicking efficiency [19]. The strong correlation between training experience and level of special fitness, including kicking power, confirms that somatic awareness developed through experience can increase kicking power [1]. While research on female martial arts trainees is limited, it underscores the significance of muscle coordination, neuromuscular training, and experience in enhancing kicking power. This finding suggests that somatic practices aimed at enhancing body awareness and control can offer substantial support to the performance of female athletes.

The kinematics of the foot at the moment of impact is a key determinant of the force generated during a kick. Higher values of kinematic variables have been shown to correlate with greater impact force, a critical factor in the effectiveness of martial arts techniques [8]. The effectiveness of the turning kick is related to biomechanical characteristics, such as peak hip flexion angular velocity and knee inversion angle of the dominant leg, which are positively correlated with effectiveness. Furthermore, the linear velocity of the lower leg has been shown to play a pivotal role in generating high-impact force [18]. Furthermore, a significant divergence in muscle activation patterns during the turning kick has been observed between novice and advanced athletes. The former demonstrates higher activation of certain muscles prior to impact, indicating an important influence of experience on neuromuscular control [10].

A biomechanical analysis of the side kick in female martial arts athletes frequently encompasses an evaluation of neuromuscular and biomechanical risk factors for injury. A comparison of the activity levels of the quadriceps and popliteal tendon in female and male athletes reveals that the former exhibit higher levels of activity in the former and lower levels of activity in the latter [2, 29]. This difference in activity levels may, in turn, increase the risk of injury during the execution of the side kick. Research indicates that the skillful use of body weight influences kicking strength [16, 22, 28]. It is acknowledged that there are inherent differences in body structure between men and women, which consequently result in divergent proportions of effective mass when executing the same movement technique. Effective mass, defined as the amount of mass involved in a punch relative to a fighter's body weight, is a key factor in effectiveness. The judo application of effective mass has been demonstrated to facilitate throws and incapacitating maneuvers [21]. It is noteworthy that effective mass does not exhibit a linear relationship with total body mass [27], but rather, it is observed to increase in conjunction with proper technique and experience [3].

In conclusion, further research is required to understand the relationship between somatic traits and kicking power in female taekwon-do athletes. Such research should analyse how body awareness and control affect power and striking effectiveness. The objective of this study is to ascertain how specific somatic traits and kinematic indices influence the force of a punch, contingent on the type of kick (i.e. turning kick and side kick). The following research questions have thus been formulated: 1) Which of the studied kicks performed by female athletes generates more force? 2) Which variables influence the force of the analyzed kicks?

This study stands out from previous research by focusing exclusively on female ITF taekwondo athletes and directly comparing the biomechanical characteristics of two different types of kicks in relation to their somatic characteristics. The results are of practical relevance to coaches who want to adapt training programmes to increase kick performance.

Material and methods

Participants

One hundred kicks were performed by five female elite ITF taekwon-do (International Taekwon-do Federation) athletes (aged 27.0 ± 4.8 years, body mass 64.2 ± 5.8 kg, height 163.0 ± 6.5 cm). To participate in the study, individuals had to meet specific inclusion criteria: they needed to be at least 18 years old, hold a minimum rank of black belt, have a minimum of eight years of training experience, actively compete at the national level for at least four years, have secured at least one Polish championship title, and be free from any injuries. The testing conditions were standardized for all participants, with assessments conducted in the morning under consistent room temperature. The testing environment featured artificial lighting provided by fluorescent lamps, which emitted a cool, white light evenly distributed across the room. This eliminated shadows and ensured optimal visibility for precise measurements and observations. The tests were conducted on puzzle mats, which were evenly placed on the floor. These mats had a non-slip surface and provided adequate cushioning, ensuring the athletes' safety during kick performance. Before testing, participants were thoroughly informed about the procedures and provided their voluntary consent to participate. All athletes were injury-free, fully briefed, and agreed to take part in the study willingly.

Ethics

The Human Subjects Research Committee of the Jan Długosz University Czestochowa scrutinized and approved the test protocol as meeting the criteria of Ethical Conduct for Research Involving Humans (KE-O/4/2022). All participants in the study were injury-free, informed of the testing procedures, and voluntarily participated in the data collection.

Equipment and Protocol

Impact force was measured using a force plate covered with a training pad to avoid direct contact during testing. The force plate, an AMTI MC12-2K model from the 2000 series (Watertown, MA, USA), featured dimensions of 305 x 406 x 79 mm and operated at a measurement frequency of 580 Hz. It was securely mounted to a stable structure to ensure accurate force measurements. The system was synchronized both temporally and spatially with the Noraxon MR3 v. 3.18 system for precise data acquisition. Participants began with a self-directed 10-minute warm-up. They then performed five right-leg side kicks (yop chagi) aimed at the force plate from a sports stance. After a one-minute rest, they executed five right-leg turning kicks (dollyo chagi) toward the same target, also from a sport stance. The procedure was subsequently repeated with the left leg. Participants adjusted the target height to suit their individual stature, ensuring the kicks were executed at an optimal level to generate maximum force. Sensors were equipped with acceleration-only attachment, allowing measurements up to 4000 g. The sensor was attached to the side of a foot, near the lateral malleolus. Throughout the testing, athletes were instructed to deliver their kicks with maximum effort to achieve the highest possible impact force. There was no time restriction imposed on the execution of the kicks. After excluding outliers, a total of 100 trials were analyzed, consisting of 50 side kick trials and 50 turning kick trials.

Data was collected at the Center for Human Movement Analysis, Jan Długosz University Częstochowa. Participants performed a self-selected 10-minute warm-up. After the warm-up, participants performed a side kick (yop chagi) to the target five times with their right leg, starting in a sports stance. After a one-minute rest, the participants performed a turning kick (dollyo chagi) five times from the sport stance to the target with their right leg. Then, the same procedure was repeated for the left leg for all participants. Participants were asked to kick with maximum effort to achieve the highest impact force they could, with no time constraints to execute the kicks.

Data processing and data analysis

The data collection process involved recording five kicks for each technique per participant. The decision to perform five trials per kick per leg was based on previous literature and designed to balance data reliability with the risk of participant fatigue. Total pressure force, foot acceleration, shank acceleration, thigh acceleration, total contact force, acceleration of the foot, acceleration of the shin, and acceleration of the thigh were recorded. Additional variables were then calculated: normalized pressure force, effective mass expressed in kilograms, and percentage of total body mass. The raw data was initially exported from the measurement software in Excel *.slk format and later converted to *.xlsx format for easier handling. Maximum force values were identified using a Python (3.12) script, leveraging the SciPy library and the “findpeaks” function to detect peak forces. These peak force values were then organized and compiled in Microsoft Excel 365 for subsequent statistical analysis. In total, 100 peak values were extracted based on the number of participants (n = 5), trials per technique (n = 5), the two types of techniques performed, and two kicking sides (left and right). The collected peak values were averaged to facilitate analysis.

Statistical analysis

The data were exported to Statistica v. 13 (TIBCO Software, Tulsa, USA) for further processing. Basic descriptive statistics were calculated, and the Shapiro-Wilk test was used to assess the normality of the data distribution. Since the data did not meet the normality assumption, the Wilcoxon test was applied to evaluate differences in the strength of selected kicks. The effect size (r) for Wilcoxon tests was interpreted as follows: values around 0.1 indicate a small effect, 0.3 a medium effect, and 0.5 or higher a large effect. Additionally, β* coefficients were calculated using a multivariate regression model, with R^2 and adjusted R^2 determined to explore potential relationships between the recorded variables. The statistical significance level was set at $p < 0.05$. Sample size estimated using G*Power software (version 3.1.9.2; Kiel University, Kiel, Germany) returned a minimum of 74 measurement positions, for $\alpha=0.05$, effect size $f=0.8$ and $1-\beta=0.95$.

Results

Table 1 presents the descriptive statistics of selected kinetic indices, which have been categorised according to the type of kick. The recorded median values for the turning kick are as follows: total pressure force (1379.13 N), normalized pressure force (22.26 N/kg), foot acceleration (129.73 m/s²). For the side kick, the median values are: total pressure force (1770.92 N), normalized pressure force (28.56 N/kg), foot acceleration (52.68 m/s²).

Table 1. Descriptive statistics of selected kinetic indicators of analyzed kicks.

Kick type	Variable	Median	Lower quartile	Upper quartile	Min	Max
Turning kick	Total pressure force [N]	1379.13	1077.60	1796.50	624.82	2150.55
	Normalized pressure force [N/kg]	22.26	21.15	43.50	10.41	34.68
	Foot acceleration [m/s²]	129.73	114.45	169.61	30.01	196.32
	Shank acceleration [m/s²]	42.87	37.61	57.52	17.82	95.52
	Thigh acceleration [m/s²]	42.39	31.33	56.91	12.24	84.99

	Effective mass [kg]	10.88	6.80	15.53	3.33	44.90
	Effective mass [%]	18.11	9.45	24.03	5.55	78.76
Side kick	Total pressure force [N]	1770.92	1238.04	3002.41	811.70	5379.02
	Normalized pressure force [N/kg]	28.56	15.32	26.35	11.73	86.75
	Foot acceleration [m/s^2]	52.68	17.84	67.11	4.25	373.67
	Shank acceleration [m/s^2]	27.59	16.53	53.99	4.57	180.41
	Thigh acceleration [m/s^2]	27.00	12.04	37.68	1.20	171.20
	Effective mass [kg]	56.85	28.00	120.03	2.32	388.24
	Effective mass [%]	85.30	47.50	193.59	3.87	626.19

Min – Minimum, Max – Maximum

The subsequent Table 2 presents the values of statistical significance, calculated on the basis of the Wilcoxon test, for the selected kinetic indicators, taking into account the type of kick. Statistically significant differences were identified between the analysed kicks in the following variables: pressure force ($Z = 6.334$, $p < 0.001$, $r=0.633$), foot acceleration ($Z = 4.776$, $p < 0.001$, $r=0.478$), shin acceleration ($Z = 2.430$, $p < 0.001$, $r=0.243$), thigh acceleration ($Z = 4.103$, $p < 0.001$, $r=0.410$), and effective mass ($Z = 5.971$, $p < 0.001$, $r=0.597$).

Table 2. Statistical significance (Wilcoxon test) of selected kinetic indicators between the analyzed kicks.

Variable	Z	p	effect size
Total pressure force [N]	6.334	$< 0.001^*$	0.633
Normalized pressure force [N/kg]	6.254	$< 0.001^*$	0.625
Foot acceleration [m/s^2]	4.776	$< 0.001^*$	0.478
Shin acceleration [m/s^2]	2.430	$= 0.015^*$	0.243
Thigh acceleration [m/s^2]	4.103	$< 0.001^*$	0.410
Effective mass [kg]	5.971	$< 0.001^*$	0.597
Effective mass [%]	5.909	$< 0.001^*$	0.591

* statistical significance $p < 0.05$

As illustrated in Figure 1, a graphical representation of the median pressure force for turning and side kicks is provided, indicating that the side kick generally achieves higher force values than the turning kick ($Z = 6.334$, $p < 0.001$).

Figure 2 provides an illustration of the β* coefficient values, based on a multiple regression model. The R^2 value of 0.715 suggests that approximately 71% of the variation in pressure force can be explained by the variables included in the model, which is a relatively high value, indicating a strong fit of the model to the data. The adjusted R^2 of 0.689 indicates that the model is a good fit, even after accounting for the number of variables. The $F(9.98) = 27.354$ value, which possesses a very low level of significance ($p < 0.001$), indicates that the regression model is statistically significant.

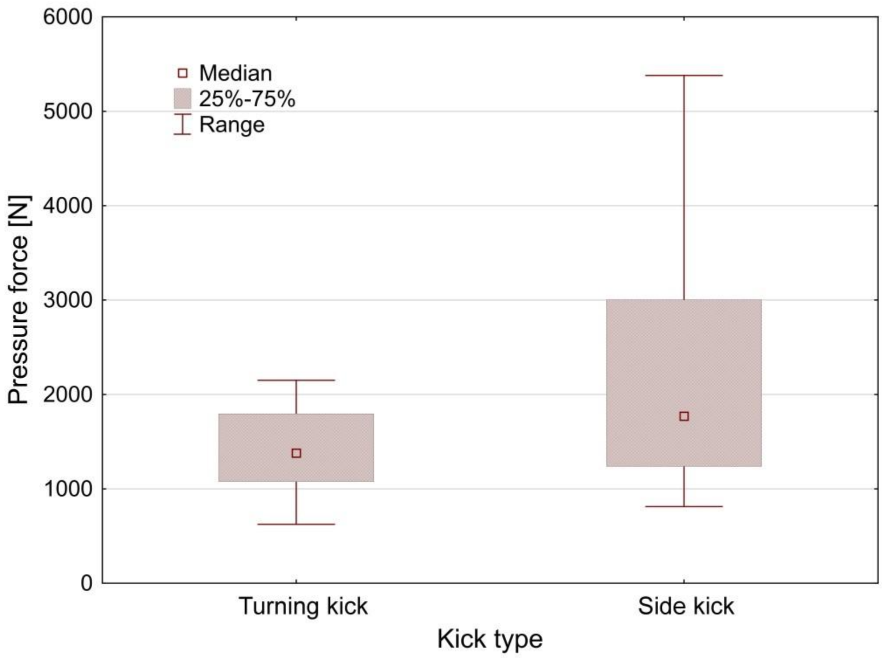

Figure 1. Graphical illustration of the median pressure force of the analysed kicks ($Z = 6.334$, $p < 0.001$).

A subsequent analysis of the effect of individual variables demonstrated that the type of kick has a significant positive impact on pressure force (β* = 0.298, t = 4.040, $p < 0.001$), indicating that a stronger kick is associated with higher pressure force. The analysis revealed no statistically significant impact of kicking with the right or left leg (β* = 0.027, t = 0.48, p = 0.630), foot acceleration (β* = -0.027, t = -0.234, p = 0.814), or thigh acceleration (β* = 0.034, t = 0.438, p = 0.661). Among the other variables, a significant positive correlation with pressure force was demonstrated for thigh acceleration (β* = 2.217, t = 3.492, $p < 0.001$), effective weight ($\beta^* = 0.359$, $t = 4.196$, $p < 0.001$), and body weight ($\beta^* = 11.578$, $t = 3.563$, $p < 0.001$). Conversely, negative relationships were observed for body height ($\beta^* = -5.103$, $t = -3.671$, $p < 0.001$) and BMI ($\beta^* = -12.724$, $t = -3.467$, $p < 0.001$). The findings suggest that effective mass, body weight, and force due to the type of kick and foot acceleration have the most significant positive impact on pressure force. Conversely, variables associated with body height exert a substantial negative influence on pressure force. The model posits that female athletes with higher body mass generate greater pressure force; however, excessive muscle development and high body height may impose limitations.

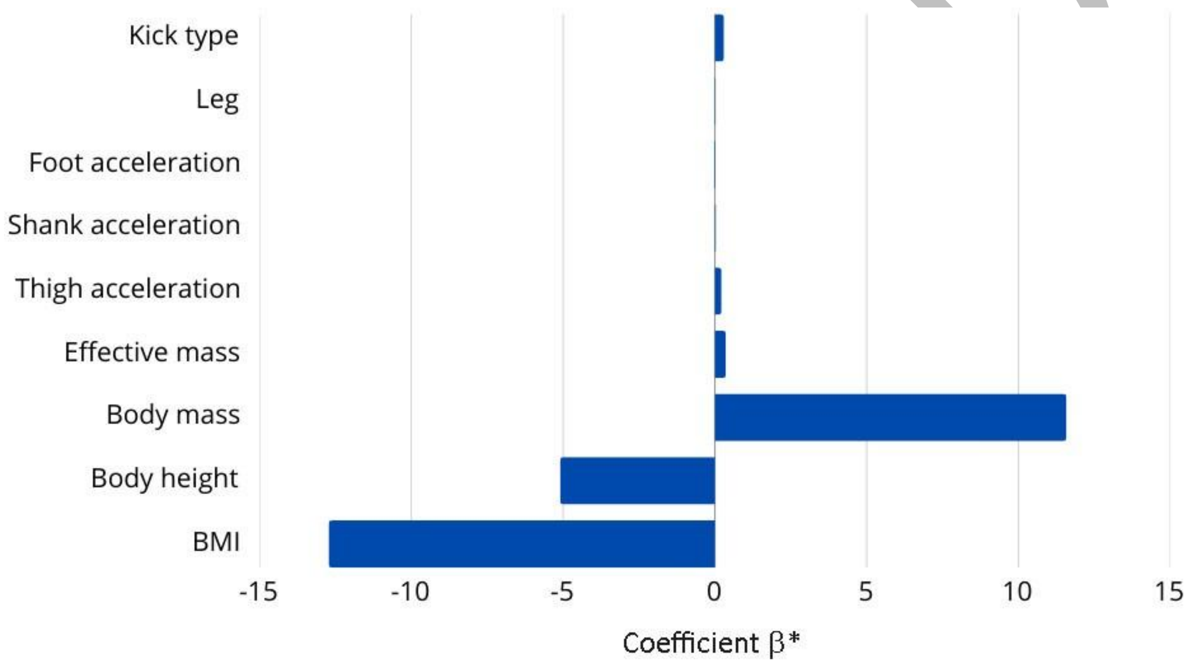

Figure 2. Coefficient β^* for variables in the regression model ($R = 0.845$, $R^2 = 0.715$, adjusted $R^2 = 0.689$, $F(9.98) = 27.354$, $p < 0.001$).

Discussion

The study demonstrated that the side kicks of female taekwon-do athletes achieved, on average, a higher peak pressure force than the turning kick. Conversely, the lower limb segments demonstrate an inverse trend in terms of average peak acceleration values. The side kick exhibited lower peak acceleration values values of the foot, shin and thigh compared to the turning kick. The values recorded are consistent with the measurements reported by other researchers [6]. It is evident that the range of variability in the variables, characterised by the minimum and maximum values, is substantial despite the advanced and experienced group of athletes constituting the subject population. The potential causes of these variations are hypothesised to be athlete specialisation and individual preferences. The competitive framework of ITF taekwon-do encompasses a variety of events, including the 'power test'. This test involves the dynamic impact of athletes on static boards. The measurement employed in this study closely mirrored the aforementioned competition. Consequently, the 'specialists' were able to obtain superior results under these conditions.

Research findings indicate that taekwon-do athletes utilise the turning kick most frequently in sporting combat [5, 24]. Consequently, the strength of the kick alone does not primarily determine the selection of the technical arsenal in this competitive environment. Studies have demonstrated that the turning kick attains a higher velocity than the side kick [12]. In addition, as posited by other authors, movement speed alone does not necessarily affect kick power [23]. Consequently, the swiftness of movement and the seamless execution of the kick, in scenarios where the environment is meticulously managed, facilitates the attainment of objectives. Conversely, in scenarios where the opponent's reaction is not a concern, and the primary objective is to maximise force generation, the utilisation of the side kick might be a superior strategy. In a self-defense scenario, the dilemma arises of whether to strike once, but with maximum force, according to the right of one option [14]. This renders it a recommended technique in emergency situations, such as the breaking down of doors or barriers to facilitate escape, due to its simple application and strong force transfer.

The effective mass values recorded in this study, expressed as a percentage of the athletes' total body mass, were approximately 18% for the turning kick and 85% for the side kick. However, given the small number of participants, the percentages obtained from the data should be interpreted with caution and are considered exploratory. In accordance with Newton's second law of dynamics, which stipulates that force is directly proportional to mass and acceleration [11], no such relationship was observed in the present measurements. The findings of these studies demonstrate that pressure force evidently increases with rising effective mass. However, no correlation was observed between the acceleration of the foot and the other segments of the lower limb. Consequently, a person with a lower total body mass, utilising appropriate movement patterns, can potentially achieve a higher or similar effective mass compared to an objectively heavier athlete. It is evident that this hypothesis requires further testing and verification.

The present study posits that female athletes with a higher total mass generate more pressure force; however, excessive muscle development and high body height can act as limiting factors. The findings of numerous researchers demonstrate that the relationship between body height and human strength is intricate and contingent on multiple factors, including muscle mass and limb length. It is hypothesised that taller individuals possess a greater capacity to develop absolute strength, given their tendency to possess greater muscle mass [20]. However, shorter individuals often exhibit a superior strength-to-weight ratio, a phenomenon attributable to the proportional relationship between body mass and height, whereby body mass increases in proportion to the cube of height, while muscle cross-sectional area (a pivotal determinant of strength) only increases in proportion to the square of height. Consequently, taller individuals tend to demonstrate higher absolute strength, yet their relative strength, measured against their body mass, is frequently diminished [13]. In combat sports, the relationship between height and punching power is multifaceted, with a number of factors contributing to this relationship. Research suggests that body mass of these athletes and their ability to generate power are more significant factors [26]. However, lower-height athletes often utilise more compact and dynamic strokes, while taller athletes may benefit from longer reach and greater leverage [15].

The calculated β* factor indicates that there are no lateralisation differences in pressure force between kicks performed with the right and left leg, which is consistent with other studies [9].

Despite the interesting results obtained, the present study has several important limitations. The number of participants was limited to five elite ITF taekwon-do athletes. The homogeneity of the study group is of great value, as it influences the reliability, relevance and interpretation of the results of the study group (women with a high level of sportsmanship), however, this may limit the generalizability of the results to a wider population. Another limitation is the implementation of measurements in a laboratory setting, separated from the dynamic context of sports combat. In addition, it would be worthwhile to include electromyographic (EMG) analysis in the future, which could provide additional information on muscle activity during the execution of kicks.

In the future, it would be worthwhile to include larger and more diverse groups of athletes, including both men and women of varying levels. It might be interesting to conduct a comparative study between taekwon-do styles (e.g., ITF vs. WT). It is also worth considering long-term intervention studies evaluating the effects of training on biomechanical parameters and kicking performance in combat sports athletes.

It is hoped that this work will partially fill the gap regarding martial arts biomechanics research, although it is only a small part of the problem. The results and considerations presented here can serve as a reference point for other researchers and can pave the way for further research.

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