

Factors influencing the effectiveness of axe kick in taekwon-do

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- B Data Collection
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Abstract

Background: Taekwon-do is famous for its powerful kicking techniques and the axe kick is the challenging one, aiming at kicking high section of an opponent. The relevance of the skill in the traditional version of taekwon-do is that a single strike might happen to reveal the winner. The main aims of the study were 1) the kinematic characteristics of the axe kick using motion capture technology and 2) the kinematics conditions leading to maximization of kick effectiveness.

Material & Methods: Six International Taekwon-do Federation (ITF) practitioners participated in the study and each of them performed the axe kick (neryo chagi) three times. Using a 3D motion capture technology, selected parameters such as maximum kick foot velocity, durations of take-off, the upswing, the downswing as well as the whole kick and the kick leg angle at maximum velocity were quantitatively determined. The basic descriptive statistics (means & standard deviations) and correlation analyses were performed for revealing the dominant factors related to the kick.

Results: The results indicate that the maximum kick power appears around 45° of the kick leg to vertical direction or 85-89% of one's body height (i.e. the optimal offence/attack height) during the downswing. The variation of the optimal offense height depends on one's body height, gender and race. And the keys for increasing the kick effectiveness are balanced weight transfer, large hip ROM for pre-lengthening hip extensors and follows an explosive foot downswing for maximizing kick-foot power.

Conclusions: The above observations: the maximal kick power occurs around 45° of the kick-leg to the vertical direction during the downswing; shortening the downswing phase could increase the axe kick quality further.

Key Words: taekwon-do • 3D motion capture • biomechanical analysis • maximal kick velocity • optimal offence height

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Taekwon-do – a Korean martial art based mainly on punches and kicks.

3D motion capture – the process of recording the movement of objects or people.

Biomechanical analysis – the use of technical sciences for the analysis of biological systems.

Axe kick – characterized by a straightened leg descending onto an opponent like the blade of an axe.

INTRODUCTION

In taekwon-do competitions, kicking skills are the skills which are mostly applied when going on the offensive. Accordingly, this sport is famous for its powerful kicking techniques [1]. The commonly used kicking techniques include front kick, turning/ roundhouse kick, back kick, side kick and axe kick. Depending on various situations of the attack, different kicking skill is selected. It is very common that points gained in individual competition count for the winner. And, it is also known that the traditional taekwon-do competitions rules award various attacks with different points [1-3]. For example, 3 points are awarded to a foot attack directed to the opponent's head, while only 1 point is awarded to a hand attack to the same location. As such, the scoring system is influencing fighting strategy applied in a competition and makes competitors focus on developing skills of foot attack directed to high section during their training.

The axe kick (in taekwon-do terminology: *neryo chagi*) is a typical kick which naturally aims at kicking high section of the opponent. Although the axe kick is a more difficult technique than the roundhouse kick, athletes prefer to take actions which eventually might prove more beneficial for them. Research shows that the kicks used most frequently in order to secure success in a competition are the roundhouse kick, back kick and axe kick [4-6].

Until recently, the latter has been investigated by rather few researchers. Tsai et al. reported that there was no significant difference in the mean kicking velocity between male and female athletes, and the kick force correlated with the pressure on the floor [7]. Berceades & Pieter made a theoretical analysis of the kinematic and kinetic aspects of the modified taekwon-do axe kick against its traditional (classical) version [8]. Tsai & Huang measured the duration of the attack made with this kick to be between 0.37 s and 0.42 s and the kicking velocity to be between 4.70 m/s and 5.55 m/s [9]. Taiwanese taekwon-do practitioners recommended using the back leg to throw this kick [10]. Tsai et al. analysed the axe kick performed by adult taekwon-do athletes and found that it was faster when initiated by the front leg (0.750 s) as opposed to the back leg (0.886 s) [11]. Most recently, Yu et al. characterized axe kick as a whip-like kicking movement during leg lift and an axe-like movement during the downward drive of the heel and concluded that hip flexibility, muscle power and whip-like movement are keys to the kick quality [12]. Additionally, Falco et al. found out that the front and roundhouse kicks are faster than the axe kick [13]. These studies aimed to identify various

factors that contribute to better axe kick by quantifying segment velocities, accelerations, joint angles and joint range of motion. Such researches have successfully yielded some insightful instructions on how to execute good axe kick; but, there are still aspects that require investigation. For example, what is an effective height range for maximizing the kick effectiveness?

It is well known that power and speed are two fundamental principles of striking and kicking in martial arts [14]. Power can be thought of as the ability to deliver enough force to off balance or knock out an opponent. Speed can be thought of as fast hand or foot movement and quick reaction. Power developed by an athlete will be wasted if he/she move/react too slow and cannot make contact, i.e. power and speed go hand in hand. A fighter needs both to be successful. In the current study, we aimed to quantify the conditions leading to maximization of axe kick effectiveness. Further, After several biomechanical studies on axe kick, it is time to update insights obtained from scientific studies for coaches and athletes to get a better understanding of the optimized kicking characteristics of the skill. Such information should help practitioners better develop goal-oriented training programs for improving learning efficiency.

The main aims of the study were 1) the kinematic characteristics of the axe kick using motion capture technology and 2) the kinematics conditions leading to maximization of kick effectiveness.

MATERIAL AND METHODS

Having adopted commonly used biomechanical analysis criteria of sports technique [15] as well as quantification means used in taekwon-do research in particular [16,17], the axe kick was broken into four stages, i.e. the initial stance (preparatory phase), foot take-off, the upswing, and the downswing. The four stages were kinematically captured and analysed using six high-speed cameras.

Subjects

The study was based on 6 taekwon-do ITF (International Taekwon-do Federation) athletes (age: 16.50±0.71 years, weight: 64.14±7.04 kg, height: 176.50±4.64 cm). The examined group included European Junior Champions, Polish Junior Champions and other athletes who had practiced taekwon-do for a minimum of 4 years. They have regular training 3 to 5 times per week. The study was approved by the ethical committee of the University of Rzeszów in Poland no. 5/2006.

Protocol

For the purpose of the standardization of a quantitative analysis, the subjects were asked to adopt the same initial stance (in taekwon-do terminology called *niunja so palmok degi maki*) and perform the axe kick three times. In total, there were 18 trials collected and analysed. The structure of the movement is presented in Figure 1 and 2.

The kinematic data collection was done by applying an Italian motion capture system called Smart-D (BTS S.p.A., Italy). The system comprised six infrared cameras, tracking the positions of reflecting markers fixed to the athlete's body. The system made it possible to record the picture of the athlete's moving body and

evaluate the kinematic parameters obtained. The use of multiple-camera motion-capture system permits considerable freedom of movement without influencing the accuracy of data, so no restrictions were placed on the movement of the subject within the capture volume and subjects could perform without having to alter their normal motor control. Using the manufacturer's specified guidelines, calibration resolution yielded results accurate to 0.3 – 0.45mm. Data was gathered at 120 frames/second, which allows the finest details of movement to be accurately examined. After positional data of markers were captured, they were applied to characterize the dynamic posture, which allowed to specify the quantitative information related to segmental coordination and timing of the athlete's movement. The general dynamic posture analysis was applied for the skill description. Further, in the analysis of unique aspects of the technique, the following factors were selected for detailed consideration: V_z – speed of the foot with regard to anterior-posterior direction (Z axis), V_y – speed of the foot with regard to vertical direction (Y axis), and V_x – speed of the foot with regard to medial-lateral (X axis) (Figure 1 & 2); as well as t_i – [s] duration of foot take-off, t_a – duration of the upswing, t_d – duration of the downswing, T [s] – total duration of the kick and α [°] – kick leg angle (orientation) at which maximum velocity was achieved.

Statistics

For quantifying the key parameters, the average values and standard deviations (SD) were calculated. Correlation analyses were applied to determine the possible relationship between the selected factors and

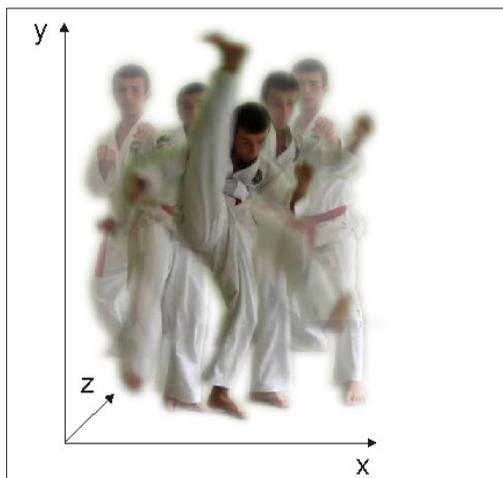


Figure 1. Diagram of the axe kick movement structure (in taekwon-do terminology referred to as *neryo chagi*) – front view

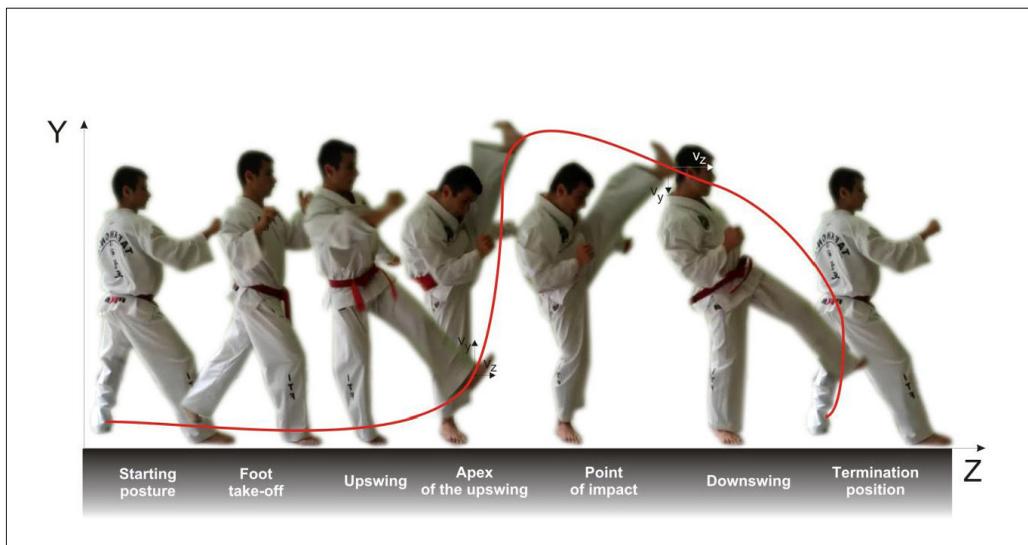


Figure 2. Neryo chagi movement structure diagram – side view. Red line – the path of the foot movement.

the maximum kick-foot velocity. The significance level for correlation analysis was set for $p < 0.05$. All the statistical analyses were performed by using MS Excel.

RESULTS

The starting posture

The athlete adopts the L-stance forearm guarding block (in taekwon-do terminology referred to as *niunja sogi palmok debi maki*) with the left foot moved forward. Both feet were slightly pointed inwards and the toes of the foot at the front were lined up with the heel of the back foot. Both knees were slightly bent. The term “initial stance” showed hints of the stance and the place where the attempted attack should start.

The foot take-off

The subjects began to transfer their weight from the back foot to the front one, moved the hips and trunk slightly forward while the arms swung slightly to the sides. During the weight transfer, they took off their right foot (i.e. the back foot) and move their whole weight onto the left foot. The downswing of the right arm and the slight backswing of the left arm provided additional energy to support the foot take-off (pursuant to the third Newton’s law of motion). The average duration of foot take-off was 0.131 s.

The foot upswing

A smooth transition from the foot take-off phase leads to the foot upswing, which on average lasted 0.514 s. There was a slight trunk flexion towards the kicking leg while the arms and the hands slightly

moved to the sides until the point when the apex of the upswing is reached.

The foot downswing

The kicking leg was slightly flexed in the knee joint. The arms were pulled back close to the trunk. This phase witnessed the point of impact, which on average took place after 0.778 s. The athletes needed to balance their whole body in such a way so that the supporting foot remained the only point of contact with the ground.

A summary of the key parameters selected in this study are shown in Table 1. The timely excursion of kick foot velocity was showed in Figure 3. These results indicated that the optimal angle at which the kick-foot velocity reached its maximum is around 44.5° and the main component of the maximal velocity is the vertical one. The correlation analyses indicated that the downswing time had highly significant correlation ($r = -0.94$) with the maximal kick-foot velocity during downswing (Table 2).

DISCUSSION

Taekwon-do is famous for its powerful kicking techniques, which can possess enough force to break bones and bricks [12]. One of the main aims of this study was to quantify the conditions leading to maximization of axe kick power.

When an athlete’s mass remains constant, a high value of foot velocity is connected with a great change of the momentum. A great momentum communicates

Table 1. Biomechanical factors affecting the effectiveness of the axe kick

Variables	Average	SD	Range
V_z [m/s] speed of the foot with regard to Z axis	5.82	1.35	3.88 – 7.61
V_y [m/s] speed of the foot with regard to Y axis	8.89	0.97	7.12 – 9.95
V_x [m/s] speed of the foot with regard to X axis	3.59	1.39	1.91 – 5.67
t_t [s] duration of the foot take-off	0.131	0.041	0.067 – 0.209
t_u duration of the upswing	0.514	0.032	0.458 – 0.550
t_d duration of the downswing	0.398	0.059	0.341 – 0.516
T [s] total duration of the kick	0.926	0.079	0.808 – 1.041
α [°] optimal angle of maximum velocity *	44.5	6.75	35 – 52

* shown in Figure 3

a great impulse of force [15]. Hence, the greater the velocity is, the greater the impulse generated by the kick. However, the maximal effectiveness of the kick is only linked to an attack at an optimum distance/height of the target for any kick [18]. Our results have shown that the maximal kick power occurs around 45° of the kick-leg to the vertical direction during the downswing (Figure 3). This finding has practical meaning for planning offence or maximizing attack effectiveness, i.e. what is the suitable range of the opponent's body height (BH) for effectively applying the axe kick? The main factor considered here is anthropometrical characteristics. A previous study [19] revealed that, percentage wise (% BH), males has longer legs and shorter trunks as compared to females, so do the Caucasians as compared to their Asian counterparts. Based on the results of both the

anthropometrical and the current studies, the relationship among BHs, the suitable offence/attack height and should heights are determined and showed in Table 3 and Figure 4.

Both Table 3 and Figure 4 suggest that Caucasian athletes could apply the axe kick effectively when the opponents are in average 4-7% taller than them. For example, a Caucasian male with body height of 1.8 m could use the axe kick to attack a 1.93-meter tall opponent effectively, while a 1.7-meter Caucasian female could do so on a 1.79-meter tall opponent. This advantage disappears for Asian athletes. They could only apply the axe kick effectively when the opponents are about the same body height or shorter than them. Unfortunately, there are no such anthropometrical data available for black population. As such, further anthropometrical studies using black subjects are needed in order to establish the standard for black athletes. Of course, coaches/practitioners could apply motion capture technology for quantifying the suitable offence height [% BH] for their athletes.

Table 2. Correlation coefficient between parameters influencing the effectiveness of the kick ($p < 0.05$).

Variables	V [m/s] Maximum kick foot velocity
t_1 [s] duration of the kick foot take-off	0.29
t_2 duration of the upswing	-0.46
t_3 duration of the downswing	-0.94
T [s] total duration of the kick	-0.78

Similar to other researches [20-22], the effectiveness of axe kick and its main contributors can be graphically summarized.

Another aim of this study was to quantitatively describe the kinematic characteristics of the axe kick using motion capture technology. Actually, after

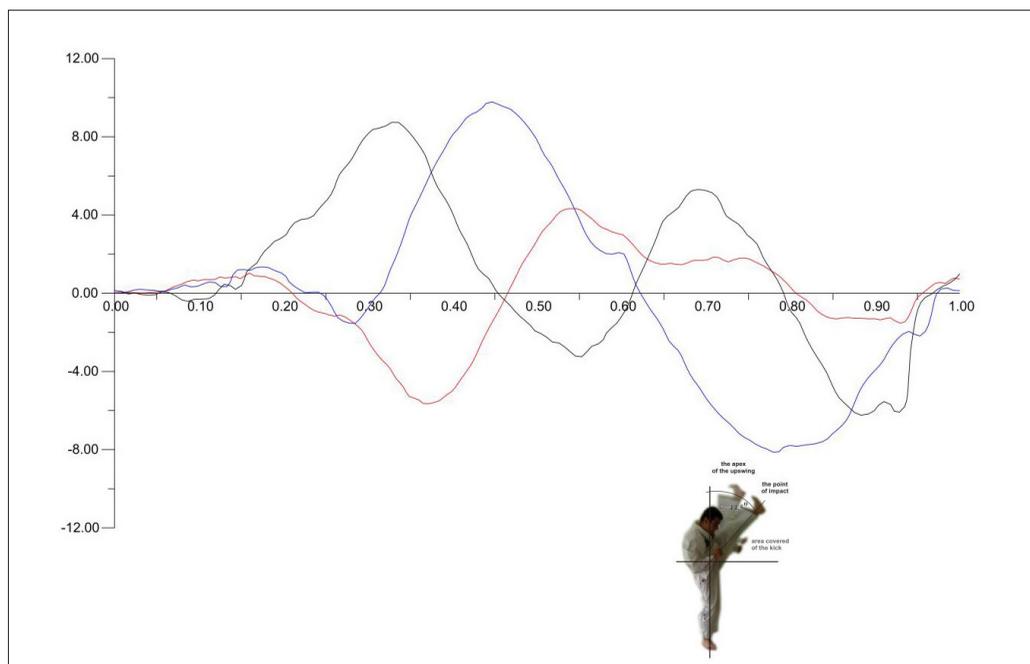


Figure 3. Timely excursion of the kick-foot velocity and the optimal offence angle of the kick-leg for reaching the maximal kick power during the downswing.

Table 3. The normalized (% BH) shoulder height and the suitable offence height of an axe kick related to gender and race.

Height (normalized by one's body height, %BH)	Caucasian		Asian	
	Males	Females	Males	Females
Standard anatomical shoulder height	86%	85%	86%	86%
Fighting-posture shoulder height	82%	83%	85%	84%
Optimal offence/attach height	89%	87%	86%	85%

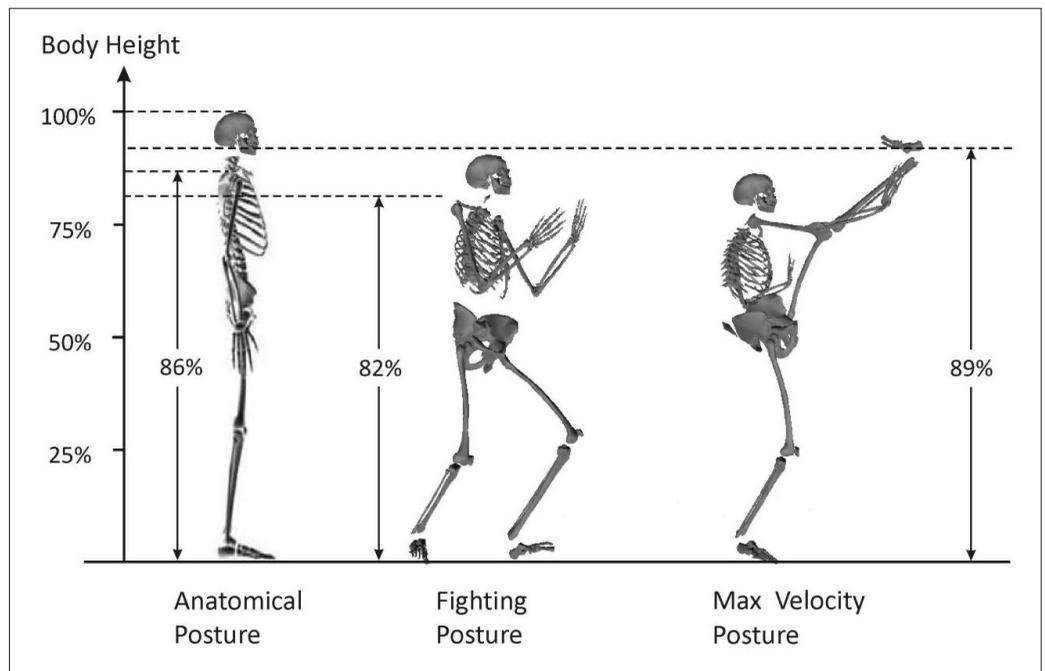


Figure 4. The relationship among body height, shoulder heights and the suitable offence height of axe kick.

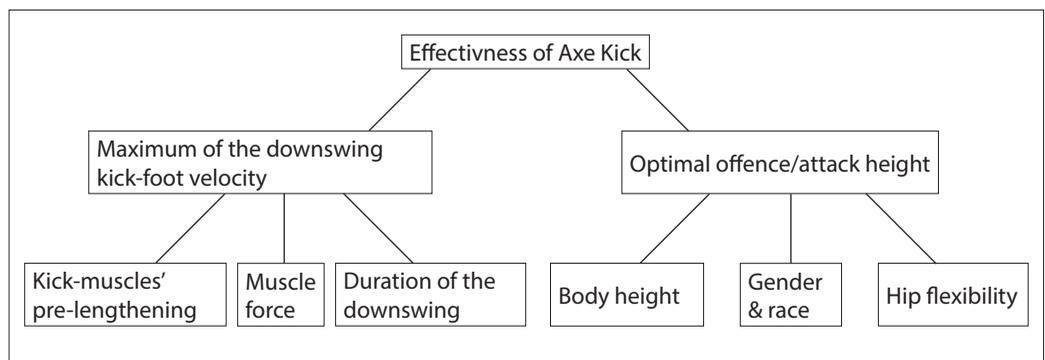


Figure 5. Factors affecting the effectiveness of an axe kick.

several biomechanical studies on axe kick, it is time to update insights obtained from scientific studies for coaches and athletes in order to get a better understanding of the optimized kicking characteristics of the skill. Firstly, from the L-stance posture to the weight transfer from the rear foot to the front one until the take-off of the rear foot signify the process of defence-to-offence. Such body transition should be fast, yet dynamically balanced, as it supplies a

foundation for upswing and downswing of the kick foot. Well balanced transition would increase the quality of an attack. Secondly, the slight trunk flexion towards the kicking leg during the kick-foot upswing would increase the ROM (range of motion) of hip joint. As such, the hip extensors would be lengthened. This dynamic muscle pre-lengthening should generate larger muscle forces based on length-tension relationships of the muscles, as such increase the effectiveness

of kicking, i.e. increasing the kick power [23]. We have not found studies related to the comparison of kick powers among various taekwon-do kicking techniques. A quantification of muscle lengthening using different taekwon-do kicks might be able to determine which type of the kicks would generate a maximal force during kicking. This will require further studies. Thirdly, the arms pull-back during the down-swing of the kick foot work as an accelerator of foot downswing as well as an assistant of dynamic body balancing. This phase is a key factor in making kicks more powerful. Previous studies using different level athletes revealed the maximum velocity ranging from 4.8 m/s to 11.3 m/s [7,11,13,24]. Collectively, these findings indicate that how-to-increase-maximal-velocity should be a focus for future studies. The current study suggests that kick-leg muscle pre-lengthening, optimal offence height and dynamic posture balancing should be the dominant aspects deserved for further investigations. Such information should help practitioners better develop goal-oriented training programs for improving learning efficiency.

Lastly, our results show that the greater the maximum velocity, the shorter the down-swing and the whole kick (Table 2). The result confirms once again that “Power and speed go hand in hand. A fighter needs both to be successful” [25]. The correlation analysis also reveals one possible relevant aspect – foot upswing which correlates surprisingly low with the maximal kick-foot velocity ($r=0.46$). Shortening the downswing phase could increase the kick quality further. At least, time (fast reaction) is often the sole difference between winning and losing a physical confrontation [26]. One cannot realize his full potential unless one can react quickly and respond accurately. One possible way for shortening the upswing

phase (or accelerating the upswing) is to use a so-called whip-like kicking movement during upswing [12]. Coaches may apply such a leg control pattern into training practice to verify its validity.

For a few years appear many publications concerning increasing the effectiveness of kicks in taekwon-do. Conclusions from presented studies are applicable in sport and in enhancing defensive possibilities of training people. Very valuable are publications that provide empirical evidence that taekwon-do might stimulate the intellectual development of man and positively affect the education of youth [27, 28].

CONCLUSION

The following conclusions have been made on the basis of the above observations: the maximal kick power occurs around 45° of the kick-leg to the vertical direction during the downswing; shortening the downswing phase could increase the axe kick quality further.

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COMPETING INTERESTS

Authors declare that we do not have any financial or personal relationships with other people or organisations that could inappropriately influence our paper.

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