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Research article

SPEED-ACCURACY TRADEOFF OF THE INSTEP KICK IN YOUNG SOCCER PLAYERS

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Abstract. *The speed-accuracy trade-off of fast movements acts inversely and as such is known as Fitts's law. The aim of this study is to determine how the instep kick (IK) speed grading instructions affect instep kick speed and accuracy. The primary hypothesis assumes that a complex motor task such as IK has an inverse relation between speed and accuracy, and the secondary hypothesis assumes that the applied speed grading instructions are sensitive. The research involved 13 male players, with an average age of 15 (±1.6). The experimental protocol included the execution of IK at five different speeds, determined by verbal instructions to the participants. For the assessment of kicking accuracy, we observed the following dependent variables: mean radial error (MRE), bivariate variable error (BVE), and centroid radial error (CRE). A comparative analysis has shown that higher accuracy (reduced MRE) and kicking consistency (reduced BVE) are achieved under lower kicking speeds, but these effects were not achieved in regard to CRE. Subsequent analyses have shown that MRE has a tendency towards a significant difference between the slowest and fastest kicks (p=0.068-0.075), while in the case of BVE it has been found that there are differences between the slowest and all other speed levels (p≤0.05). The main findings of this study have indicated a partial existence (two of three variables) of an inverse relationship between speed and accuracy in complex motor tasks such as IK.*

Key words: *kicking technique, motor control, Fitts's law*

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INTRODUCTION

Soccer belongs to the group of polystructural activities of a complex character (Kocić, Joksimović, & Stevanović, 2016) that requires a high level of psycho-physical and technical-tactical abilities. An analysis of the technical-tactical aspect of a soccer game indicates that a soccer player contacts the ball 51 times in 90 minutes, 51% of which is kicking the ball (Mohr, Krustrup, & Bangsbo, 2003), and for this reason a good kicking technique represents an important segment of a soccer game. One of the most frequently used kicks in soccer is the instep kick (IK), i.e., kick of the ball with the front part of the foot, therefore its improvement is seen as an important segment of soccer technique. The speed and accuracy of the IK are the two dominant factors on the basis of which the success of execution of this technical element is determined. If the execution of the IK on the goal is considered, fast kicking is important because the speed of the ball surprises the opponent, i.e., the goalkeeper, reducing his ability to react, while on the other hand, kicking with high accuracy pushes the ball away from the opponent, preventing him from catching it.

The speed-accuracy trade-off is theoretically described within Fitts's law, according to which there is an inverse relation between these two variables, shown as a ratio of functions of speed and accuracy (Fitts & Peterson, 1964). Thus, giving instructions to carry out the movement more accurately reduces speed, and vice versa. The majority of results describing the ratio of speed and accuracy were obtained in studies involving simple single-joint movements (Fitts & Peterson, 1964). However, the results obtained in the execution of fast, ballistic and discrete movements, such as throwing and shooting, show certain deviations from the theoretical approach (Van den Tillaar & Ettema, 2003; Van den Tillaar & Ulvik, 2014). In particular, Van den Tillar & Ettema (2003) have shown that when executing throwing tasks with accuracy as the dominant instruction in carrying out a motor task, the speed of execution decreases, with no improvement to accuracy, which goes against Fitts's law models. A detailed relation of mutual dependence between speed and accuracy of the executed IK is given in Van den Tillaar and Ulvik's research (2014). The aim of this research was to examine the effect of instructions on the speed-accuracy trade-off of a kicked ball with dominant and non-dominant leg. The obtained results in this study have shown that the instruction focused on accuracy affected the reduction of dominant and non-dominant leg speed, but also, the same instruction resulted in an increase of kicking accuracy, but only in regard to the dominant leg. This has shown that Fitts's law only relates to the dominant leg in this case.

The speed-accuracy trade-off, wherein the mutual negative transfer of variables is minimal, represents the main goal of improving IK execution. The optimal ratio of speed and accuracy of a kicked ball is the result of a combination of several different variables. Kicked ball speed is measured by a manual radar and the obtained results are interpreted in relative and absolute values. On the other hand, the precision of the executed kick in the previous research was most often assessed indirectly with simple variables such as: the number of points (Reilly & Holmes, 1983; Rösch et al., 2000; Haaland & Hoff, 2003; Ali et al., 2007); number of scored goals per game (Starosta, 1988); number of kicks to the goal per game (Zeederberg et al., 1996); number of hits between two markers (McLean & Tumilty, 1993), and accuracy assessment by independent judges (Uppal & Roy, 1986). However, the mentioned variables have numerous methodological limitations (Finoff, Newcomer, & Laskowski, 2002). The effect of the executed kick in the context of the observed accuracy can be assessed directly, with a few more valid and more sensible measures. In this regard, Hancock, Butler, & Fischman (1995) and Kim et al. (2000) proposed the introduction of standard errors for assessment of accuracy of corresponding two-dimensional tasks. The most common standard errors used in direct assessment of accuracy of soccer kicks are (Russel, Benton, & Kingsley, 2010; Bačvarević et al., 2012): absolute error (accuracy measure), constant error (deviation measure) and variable error (consistency measure). When it comes to the effect of the accuracy of instruction on kicking speed, and vice versa, there is one unexplored area. In previous studies, it was pointed out that focusing on accuracy reduces speed, which means that the reduction of speed is a consequence of increased demands to kick more accurately, where a motor task is typically executed with two instructions: hit the target or kick as fast as possible. In this regard, the question arises as to how the change of speed that is graded on multiple levels affects the errors. Early studies have shown that when the emphasis of the instruction is placed on kicking accuracy, the speed is reduced from 75% to 85% in relation to the maximum (Van den Tillaar & Ulvik, 2014; Lees & Nolan, 2002; Andersen & Dörge, 2011), but it is unknown whether the error continues to decrease if the speed decreases below these values.

In this regard, the aim of the research was to use the IK speed grading instructions to investigate the effect on: a) kicking speed and b) kicking accuracy. Considering the previous research on which Fitts's law is based, a primary hypothesis was established that the change in speed inversely affects the error (accuracy) occurring in the execution of IK and that the least amount of errors occur in the minimum speed range. The secondary hypothesis assumes that the applied speed grading instructions will be sensitive. The conducted research has a theoretical and applicable context. The theoretical significance of the research is primarily the application and confirmation of Fitts's law, while the applicable context is related to the effect of the instruction on kicking accuracy.

METHODS

The sample of participants

The study involved 13 male participants, with an age of 15±1.6 years, average height of 180.4±5.1 cm and average weight of 70.3±5.8 kg. The participants were soccer players from the Belgrade-based "Crvena zvezda" and Ub-based "Jedinstvo" soccer clubs, who spent at least 5 years in an organized soccer training process. The participants were all players who play in different positions on the team, except for the goalkeeper.

Procedure

All experiment measurements within the realized research were carried out at the First National Training Center of the Serbian Institute of Sport and Sports Medicine in Belgrade, in the period from the beginning of October to the end of December 2015.

Before the tests began, all of the participants went through standard 15-minute warm-up exercises that consisted of warm-up running, body toning exercises, active stretching, two-foot standing jumps, and IK simulation exercises without a ball. Upon completion of the warm-up, the participants executed the IK to the goal for 5 minutes in order to familiarize themselves with the kicking technique and with the distance of the ball from the target. After completing this part of training, the IK execution started with the same instructions given in the main test. Three kicks were executed in accordance with the motor task, i.e. the given instruction. After familiarizing with the test, the main testing of all the participants commenced.

In relation to testing the impact of the kicking speed factor on kicking accuracy, the speed grading instructions were used. All of the participants were given specific instructions for executing the IK with the aim of obtaining different levels of speed for the following motor tasks:

- hit the center of the target with a slow kick (instruction B1);
- hit the center of the target with a slightly faster kick (instruction B2);
- hit the center of the target with a kick of maximum speed (instruction B3);
- hit the center of the target with a kick of maximum speed with a secondary focus on accuracy (instruction B4);
- execute a target-orientated kick of maximum speed (instruction B5).

The target was visually represented by a 50×50 cm square. The width of its black-colored sides was 5cm. All kicks were executed from a distance of 9 meters from the target (Figure 1). The target used in this experiment was made of a 5cm thick and 5cm wide sponge, placed on a frame made of a wooden board, sponge and memory foam, attached to the wall. The frame was constructed by placing a 4m wide, 2m tall and 2cm thick plywood board on the wall, covered with a 5cm thick layer of sponge and a 3cm thick layer of foam. This layering made it possible for ball imprints to linger, which was important in order to determine and extract the moment of contact between the ball and the target with the video camera in further analysis more easily.

In order to make it easier and more precise to determine the position and size of the ball imprint during its contact with the wall, a multiplatform application was developed in Java programming language (Figure 2). The purpose of the application was to determine the coordinates of the contact center in the coordinate system defined by reference points (points A, B, C, D in Figure 2) on the wall (the points must be visible on the image), in the series of images made at the moment of contact of the ball with the wall.

The approach angle of the ball is one of the most important aspects that has a significant impact on IK ball speed and accuracy (Isokawa & Less, 1988; Kellis, Katis, & Gissis, 2004; Opavsky, 2011; Roberts et al., 1974), so it was important to standardize the approach angles for all the participants. The ball approach angle was defined in the range of 30o to 60o in relation to the direction determined by the position of the ball and target. In previous studies, it was found that the ball approach within the range of 30o to 60o creates optimal conditions for achieving the highest kicking speed and best accuracy (Isokawa & Lees, 1988).

The length of the participants' approach was not determined; instead the participants estimated the optimal length of the approach appropriate for execution of these motor tasks during the process of familiarization with the test. The approach length optimization principle was valid in various previous research, i.e. the participants themselves determined the approach length (Lees & Nolan, 1988; Opavsky, 2011; Gheidi & Sadeghi, 2010; Van den Tillar & Ulvik, 2014), therefore this method was also used in this experiment.

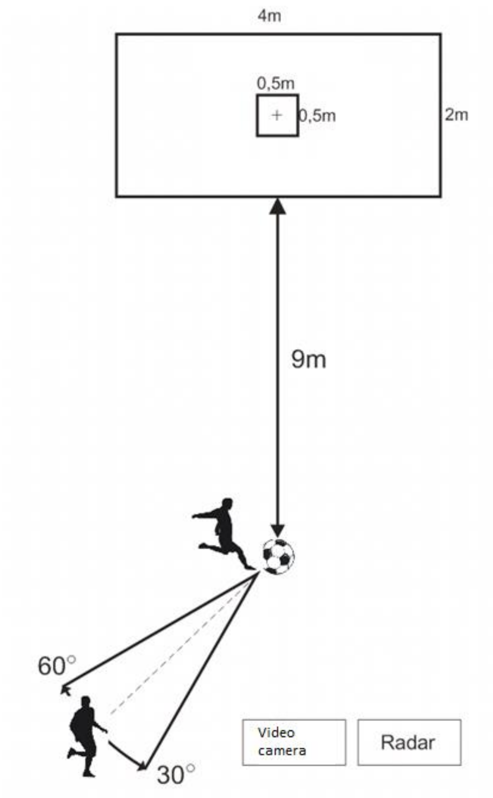

Fig. 1 Illustration of the experimental setting in test execution

Measurement methods

Two measurement units were used during the data collection process. One unit measured and recorded the achieved ball speeds and numbers of shots for the executed kicks. The second unit recorded the executed kicks with a video camera.

The speed of the ball was measured by a manual radar for speed estimation (Sports Radar Speed Gun SR 3600, Homosassa, FL, USA).

Each kick was recorded with a camera with a recording frequency of 50 Hz (Canon EOS 600D, Japan).

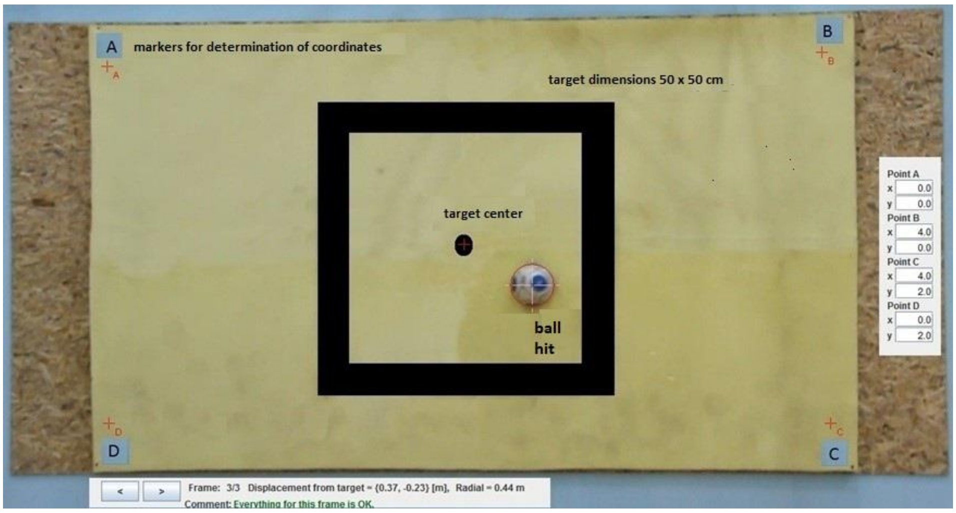

Fig. 2 Overview of the multiplatform application for measuring the executed kick accuracy

Sample of variables

In order to test the set objectives, the following variables were defined:
- Ball speed (BS) expressed in kilometers per hour (km/h),
- Relative ball speed (BSrel) expressed in percentage relative to the maximum kicking speed (%).
- Mean radial error (MRE), used for accuracy assessment, expressed in centimeters (cm),
- Bivariate Variable Error (BVE), used for consistency assessment, expressed in centimeters (cm),
- Centroid Radial Error (CRE), used for deviation assessment, expressed in centimeters (cm).

It is necessary to note that all variables for kicking accuracy assessment (MRE, CRE and BVE) were used in the two-dimensional coordinate system, so if an analogy with standard errors monitored in the one-dimensional system is made, the MRE would be an absolute error, BE-variable error, and CRE-constant error.

Data processing

Further analysis of the achieved accuracy gave results for selected standard errors calculated using the following formulas (Hanckok et al., 1995):

$$MRE = \overline{RE} = (1/n) \sum_{i=1}^{m} (RE_i)$$

$$RE = (x^2 + y^2)^{\frac{1}{2}}$$

$$BVE = \{(1/n) \sum_{i=1}^{n} [(x_i - x_c)^2 + (y_i - y_c)^2]\}^{\frac{1}{2}}$$

$$CRE = (x_c^2 + y_c^2)^{\frac{1}{2}}$$

$$(x_c, y_c) = (\bar{x}, \bar{y}) = [\frac{1}{n} \sum_{i=1}^{n} x_i, \frac{1}{n} \sum_{i=1}^{n} y_i]$$

For each of these formulas, *n* represents the number of executed kicks, *x* and *y* values represent the distance from the center of the hit from the vertical (Y) and horizontal axis (X), and RE represents the participant's radial error.

Statistical analysis

Representative measures of mean values and standard deviations were used from the descriptive statistics. The normality of distribution of the results was analyzed by the Shapiro-Wilk test. In order to determine the effect of kicking speed on IK accuracy, the data was processed by a variance analysis (ANOVA) with repeated measurements. For each group of variables, the results' sphericity assumption was first determined using Mauchly's test. In cases where the sphericity assumption was not met, i.e. the values of Mauchly's test showed p values less than 0.05, the Greenhouse-Geisser correction for df and F values was used. In cases where the ANOVA detected the existence of a significant effect of execution speed on one of the dependent variables, Bonferroni's post hoc analysis was carried out to test the differences between different kicking speeds. Effect size was used for the assessment of possible differences, represented as the partial exponent Eta ($p\eta^2$), calculated separately for each of the main effects and interactions of the applied ANOVAs. The values of $p\eta^2$ of 0.01, 0.06 and 0.15 were considered small, moderate and large, respectively. Also, statistical power (1-β) was used to assess the probability of the obtained differences. The value of $p<0.05$ was selected for determining the level of statistical significance. All statistical analyses were carried out in the program for statistical processing of results SPSS 17 (SPSS Inc., Chicago, IL, USA).

RESULTS

Figure 3 graphically shows the descriptive values for variables used for the assessment of the kicked ball (BS and BSrel). The results show that the speed of the ball (absolute and relative) increased in accordance with the application of appropriate instructions for IK execution, from the slowest (B1) to the fastest (B5) kick.

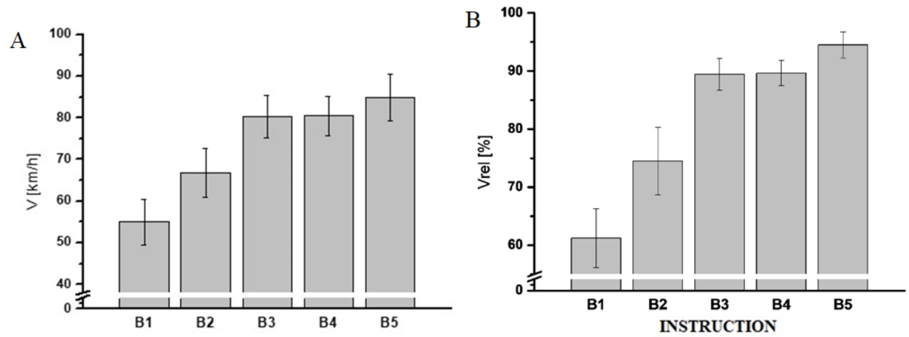

Fig. 3 Average values with standard deviations for variables: A) Ball speed (BS) and B) Relative ball speed (BSrel) for applied kick speed grading instructions
Note: The marks on the x-axis represent the applied speed grading instructions, from the slowest (B1) to the fastest (B5) kick

For both variables used to describe the kicked ball speed (BS and BSrel), the ANOVA results with repeated measurements indicated that there was a significant effect of the IK speed grading instruction (Table 1).

Table 1 Overview of ANOVA results with repeated measurements for the effect of applied speed grading instruction on the variables for kicked ball speed assessment.

	F	p	$p\eta^2$	1-β
BS	197.7	0.00	0.94	1.00
BSrel	216.1	0.00	0.95	1.00

Legend: F- frequency; p – significance level; $p\eta^2$– effect size; 1-β – statistical power; BS – ball speed; BSrel – relative ball speed

Post-hoc analyses have also shown consistent results for both variables, i.e. it was shown that there is a significant difference between each level of execution speed ($p\leq0.002$), except between instructions B3 and B4, where no difference in values has been observed (p=1.000). Figure 4 graphically shows the descriptive values for variables used for accuracy assessment in the two-dimensional coordinate system (MRE, BVE and CRE). The results show that the error rate for variables MRE and BVE was the smallest when applying instructions for the slowest kicks (B1), and the highest in instructions for the fastest kicks (B5). However, when it comes to the CRE variable, the obtained results have not shown clear patterns of obtained errors in relation to applied instructions for kicking speed grading.

The ANOVA results with repeated measurements have shown that there is a significant effect of the IK execution speed grading instruction on the MRE and BVE variables, while this was not the case with CRE (Table 2). Post hoc analysis has shown that there is a tendency towards a significant difference in the MRE results, in instruction B5 in comparison to instructions B1 and B2, where major errors were achieved with instruction B5 (p=0.075 and p=0.068). There were no significant differences between other instruction modalities. A post hoc analysis has shown that BVE was significantly lower in instruction B1 compared to instructions B3, B4, and B5 ($p\leq0.05$), while significant differences were not obtained among other modalities.

Table 2 Overview of ANOVA results with repeated measurements for the effect of applied speed grading instructions on kicking accuracy assessment

	F	p	$p\eta^2$
MRE	3.7	0.01	0.24
BVE	3.8	0.01	0.24
CRE	0.8	0.52	0.06

Legend: F- frequency; p – significance level; pη2– effect size; 1-β – statistical power; MRE – mean radial error; BVE- bivariate radial error and CRE – centroid radial error

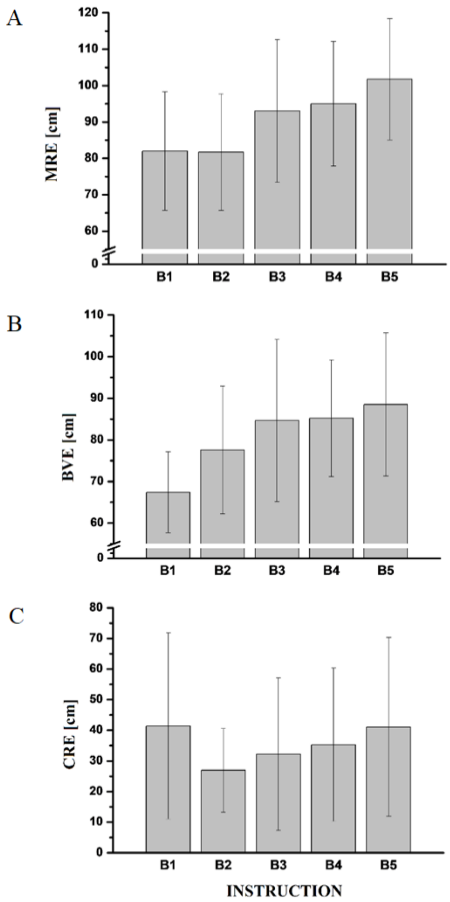

Fig. 4 Average values with standard deviations for variables: A) Mean Radial Error (MRE); B) Bivariate Variable Error (BVE); and C) Centroid Radial Error (CRE), for applied kick speed grading instructions

Note: The marks on the x-axis represent the applied speed grading instructions, from the slowest (B1) to the fastest (B5) kick

DISCUSSION

The main aim of this experiment was to determine the effect of the IK execution speed on kicking accuracy, i.e. to determine the optimal range of speeds at which the least errors occur. For the purpose of testing the effects of different kicking speeds on error rates, IK speed grading instructions were defined and variables observed for the assessment of: a) ball speed (BS and BSrel) and b) kicking accuracy (MRE, BVE and CRE). The results have shown that there is a sensitivity of speed grading instructions, since the assumption that they affect the speed of the kicked ball (BS and BSrel) has been confirmed. Based on the review of previous research, it was assumed that kicking speed will act inversely on the achieved kicking accuracy, which is partly proven with the obtained results. More precisely, the main findings of this study have shown that increasing the speed affects the increase in the MRE value (i.e. the decrease of kicking accuracy), as well as the increase in the BVE value (i.e. the decrease of kicking consistency). A detailed discussion of the obtained results is divided into two parts. The first part analyses the effects of speed grading instructions on kicking speed variables, i.e. to what degree the participants have been sensitive to the introduced experimental factor in the form of the instructions they received, with the aim of forming different ranges of kicking speed. The second part analyses the effects of speed grading instructions on kicking accuracy variables.

Effect of speed grading instructions on ball speed

The results of the study have shown that there is an expected significant effect of speed grading instructions on the observed ball speed variables (BS and BSrel). The results obtained for BS show that the slowest speed was achieved by the instruction for hitting the target with the slowest kick (B1), and the highest speed by the instruction whose only focus was the speed of the ball (B5), where the obtained speed was 84.9 km/h. The obtained ball speed results for the B5 instruction are somewhat smaller than the results obtained by a similar instruction in the Lees & Nolan (2002) study, which was 91.8 km/h. This can be explained by the participants, who in the Lees & Nolan study (2002) were senior professional soccer players, while the participants in this study were aged between 14 and 16. As can be seen, different speed grading instructions have achieved the required speed grading, except between levels B3 and B4. It is important to highlight this result which explains that participants could not grade the kicking speed between B3 and B4, which were defined in the following way: "hit the center of the target with a kick of maximum speed" (B3) and "hit the center of the target with a kick of maximum speed with a secondary focus on accuracy" (B4). When establishing the experimental methods, the intent was to set five different levels of kicking speed. However, with instructions given in this manner it was obviously not possible to grade the speed at five different levels. It is necessary to note that the authors of the Tillar & Ulvik (2014) study used only four levels of speed grading instructions, which additionally corroborates the results obtained in our research. By relativizing the achieved ball speed results (BSrel), it is noted that the applied instructions cover the range of moderate and high speeds, and that instruction B1, i.e. hitting the target with the slowest kick, results in the average ball speed of 61%, while instruction B5 results in 94% of the maximum values. The results of speeds expressed in relative values show more clearly the obtained grading of speed. Analyzing the obtained results, it can be said that the set hypothesis has been confirmed to a greater degree and that the applied instructions are sufficiently sensitive (four out of five), and as such they can be further used in training and experimental processes.

Effect of speed grading instructions on kicking accuracy

The obtained results show that the speed grading instructions affect MRE as a measure of absolute precision and BVE as a measure of kicking consistency. These findings can be discussed further from theoretical and practical aspects. With regards to the theoretical aspect, in two out of three variables for assessing kicking accuracy, there is an inverse relationship between speed and accuracy in a complex motor tasks such as IK (a multi-joint and discrete motion), which confirms the established hypothesis to a great extent. This is in line with Fitts's Law (REF), as the decrease in kicking speed results in an increase in kicking accuracy and consistency, and that the least errors for these two kick characteristics were achieved at the lowest kicking speeds.

Analyzing from a practical aspect, the results obtained regarding the ratio of speed and accuracy show that, on average, the most accurate kicks (estimated by MRE) were achieved at ball speeds of 61% to 74% (instruction B1 and B2), while the kicking accuracy decreased by increasing kicking speed, especially in relation to the fastest kicks (instruction B5). These results are in line with the results of the Van den Tillaar & Ulvik (2014) study, which found that the most accurate kicks were achieved at 73% of the maximum ball speed. Through a more detailed review of the references, we found different ratios of speed and accuracy, so in this way it was found that the most accurate kicks were achieved at speeds of 75% of the maximum (Lees & Nolan, 2002), and 85% (Andersen & Dorge, 2011). Indermill & Husak (1984) concluded that the fast throwing movements are most accurate at speeds of 75% of the maximum. Bearing in mind that in the results of this study the error significantly increased at speeds over 90% in relation to the maximum speed, they agree with the findings of earlier researchers reporting that at a speed greater than 85% there is a significant increase in errors (Cauraugh, Gabert, & White, 1990), or at speeds greater than 92% (Van den Tillaar & Ulvik, 2014). The results show that, on average, the most consistent kicks (calculated by BVE) were achieved at ball speed of 61% of the maximum (instruction B1). With a further increase in kicking speed, the kicking consistency is significantly reduced, i.e. the achieved hits in the target become significantly diluted, especially at speeds of over 89% of the maximum. However, it is important to note that the kicking consistency was not significantly changed when the IK was executed at submaximal and maximum speeds (instructions B2-B5), so moderately fast kicks had a similar dilution of hits as maximum fast kicks.

CONCLUSION

Based on the results obtained in this study, it can be concluded that the obtained findings support with the set hypothesis. From the theoretical point of view, the findings of this study confirm that Fitts's law applies to complex motor tasks such as IK in soccer, in situations where different requirements on speed and accuracy are imposed. The practical significance of the obtained findings is reflected in the justification of the further use of verbal instructions in the training process of training soccer technique. In particular, IK speed was largely sensitive to the given speed grading instructions and changed with the expected trend. Also, the speed-accuracy trade-off is supported by Fitts's law, so it is noted that the accuracy decreases with the increase in kicking speed, and vice versa. In order to provide the optimal speed-accuracy trade-off, trainers are recommended to use the instruction to kick the ball with focus on the middle kicking speed in technical training of players during IK execution, since instructions B3 and B4 have achieved ball flight speed of approximately 80 km/h due to a negligible reduction in accuracy (MRE: 81.76 cm), in relation to the maximum accurate kicks (MRE: 82.03 cm), which are executed at the lowest speeds. On the other hand, one should bear in mind the conclusion of some authors who emphasize that, in situational conditions of training and competition, faster kicks with a slightly worse accuracy are more effective compared to extremely accurate kicks achieved at low speeds (Van den Tillaar & Ulvik, 2014), and with this in mind, the above mentioned recommendations for instructions suitable for improving IK execution will not be valid if the aim of the training process is to improve kicking speed.

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ODNOS BRZINA-TAČNOST UDARCA UNUTRAŠNJOM STRANOM STOPALA MLADIH FUDBALERA

Odnos brzina-tačnost brzih pokreta deluje obrnuto proporcionalno i poznat je kao Fittov zakon. Cilj ove studije bio je da utvrdi kako instrukcije udarca unutrašnjom stranom stopala (IK) utiču na brzinu i preciznost udarca. Primarna hipoteza pretpostavlja da složeni motorni zadatak kao što je IK ima inverzni odnos između brzine i tačnosti, a sekundarna hipoteza pretpostavlja da su primenjene instrukcije za ocenjivanje brzine osetljive. Istraživanje je obuhvatilo 13 igrača muškog pola, prosečne starosti od 15 godina (± 1.6). Eksperimentalni protokol je uključio izvršenje IK pri pet različitih brzina, saopštenih ispitanicima verbalnim putem. Za procenu tačnosti udaraca, posmatrane su sledeće zavisne varijable: srednja radijalna greška (MRE), bivarna varijabla greške (BVE) i radijalna greška centroida (CRE). Komparativna analiza je pokazala da se veća tačnost (smanjena MRE) i konzistentnost udaraca (smanjena BVE) postižu pri nižim brzinama udaranja, međutim ti efekti nisu postignuti u odnosu na CRE. Naknadne analize su pokazale da MRE ima tendenciju ka značajnoj razlici između najsporijeg i najbržeg udarca ($p = 0.068$-0.075), dok je u slučaju BVE ustanovljeno da postoje razlike između najsporijeg i svih ostalih nivoa brzine ($p \leq 0.05$). Glavni nalazi ove studije ukazali su na parcijalno postojanje (dve od tri varijable) inverzne veze između brzine i tačnosti u složenim motornim zadacima kao što je IK.

Ključne reči: *tehnika udarca, motorna kontrola, Fittov zakon*