



DIFFERENTIAL CONTRIBUTION OF REACTION TIME AND MOVEMENT VELOCITY TO THE AGILITY PERFORMANCE REFLECTS SPORT-SPECIFIC DEMANDS

doi: 10.1515/humo-2016-0013

ERIKA ZEMKOVÁ

Department of Sports Kinanthropology, Faculty of Physical Education and Sports, Comenius University in Bratislava, Slovakia

ABSTRACT

Purpose. This study estimates the contribution of reaction time and movement velocity to the reactive agility time while covering varied distances. **Methods.** A total of 95 athletes of karate, hockeyball and soccer participated in a simple reaction, two choice reaction, step initiation and reactive agility test. **Results.** Agility time was significantly better in karate-kumite than karate-kata practitioners when covering a distance of 0.8 m (8.2%, $p = 0.045$), better in hockeyball players than goalies when covering a distance of 1.6 m (10.9%, $p = 0.028$) and better in soccer players than goalies when covering a distance of 3.2 m (14.2%, $p = 0.009$). Movement velocity to agility time contributed to a lesser degree in the case of karate-kata competitors, hockeyball and soccer players (33.5%, 28.3%, and 19.9% respectively) than the karate-kumite competitors, hockeyball and soccer goalies (44.2%, 42.7%, and 39.4% respectively). Furthermore, both simple and two choice reaction times were highly related to the agility time when covering distances of 0.8 m, 1.6 m, and 3.2 m (r in range from 0.72 to 0.88). Movement velocity also significantly correlated with the agility time in the test with a distance of 0.8 m ($r = 0.76$) but not with longer movement distances of 1.6 ($r = 0.61$) and 3.2 m ($r = 0.52$). **Conclusions.** Reaction time and movement velocity differentially contribute to the agility time in athletes of varied specializations. This reflects their specific demands on agility skills, and therefore should be addressed in agility testing in order to identify an athlete's weakness.

Key words: reactive agility, reaction, step initiation, testing

Introduction

For many years, agility was classified as the ability to execute rapid movements and the capacity to stop and restart quickly. As a result, the majority of agility research was devoted to pre-planned and change-of-direction speed tests. Eventually, agility tests that combined change of direction speed and cognitive measures were developed. These reactive agility tests also included anticipation and decision-making components in response to the movements of a tester. Sheppard et al. [1] discovered that the reactive agility test differentiated between players of varied performance levels in Australian football, but traditional closed skill sprint and sprint with direction change tests did not. As a result, agility has been redefined as a rapid whole-body movement, with change of velocity or direction in response to a stimulus [2]. This definition implies three information-processing stages: stimulus perception, response selection, and movement execution.

The first two components of agility performance can be indirectly estimated by measuring the simple and multi-choice reaction time. Reaction time figures prominently in the open skills required in many sports (e.g., boxing, ice-hockey). Take baseball, for example. The entire trajectory of a pitch in baseball might measure only 400 ms and the bat swing may take 120 ms to execute. Thus, if a batter takes an extra 100 ms to detect the speed and trajectory of the pitch, this could severely

limit the chance of successful contact [3]. Equally, processing delays in a sprinter or goalie may significantly impact their performance. An individual who has the ability to minimize such delays has an advantage in events such as the 100-m dash or when catching a ball.

Decision time strongly influences total reactive agility time, therefore it is important to address perceptual skills in agility testing and training. Young and Willey [4] discovered that of the three components that make up the total time, decision time had the highest correlation ($r = 0.77$, $p = 0.00$) with the total time. This correlation with total time was greater than for the response movement time ($r = 0.59$) or tester time ($r = 0.37$), indicating that decision time is the most influential of the test components for explaining the variability in total time. The decision time component within the reactive test condition also revealed that highly-skilled players made significantly faster decisions than the lesser skilled players [5]. Also, as the results of Gabbett and Benton [6] demonstrate, decision and movement times in the reactive agility test were quicker in more highly skilled players, without compromising response accuracy. Similarly, Serpell et al. [7] revealed a significant difference in mean time in the sport-specific reactive agility test (RAT) between the elite group and the subelite group of the rugby league. Performance differences on the RAT were attributed to differences in perceptual skills and/or reaction ability. The review of Paul et al. [8] showed that decision-making and perceptual factors are often propositioned as

discriminant factors; however, the underlying mechanisms are relatively unknown.

The third component of agility performance is movement execution. To evaluate the speed of step initiation, one can perform simple or two-choice stepping reaction test to visual stimuli. The test begins with the subject standing on two mats placed in front of a light signal. When the light is activated, the subject performs two steps towards mats placed 60–70 cm apart and marked with tape on the floor. The time from foot-off (onset of unloading) and foot contact time (from foot-off to foot-contact) is recorded. However, due to problematic issues in reproducing the task, plus a lack of acceptable precision when compared to accurate laboratory tests, the practicality of using the visually-triggered step initiation test is limited, especially when quantifying slight changes in performance of individuals and small groups [9]. Therefore, it is preferable to utilise the diagnostic system based on a precise analogue velocity sensor with a sampling rate of 100 Hz to measure the velocity of step initiation. This measurement is more reliable and better equipped to distinguish between individuals of different ages and levels of physical fitness [10]. Since there is a significant relationship ($r = 0.837$) between the foot contact time (from foot-off to foot-contact) and the maximal velocity of the step, such measurement may be a viable alternative to the previous test.

Performance in the change of direction test more strongly correlates with acceleration speed than with maximum running speed [11–13]. Therefore, stronger correlation may be assumed between maximal step velocity and agility time over a shorter than longer distance. Recently, Sayers [14] reported that measuring change of direction speed over a distance of 1 m provides an effective compromise between test reliability and the need to discriminate change of direction ability from high-speed linear running ability. The proportionally weaker correlations between high-speed linear running ability and change of direction speed measures for distance ≤ 1 m suggest that the distance over which change of direction speed is measured currently (≥ 5 m) may be too long.

Our experience also showed that athletes prefer distances shorter than 5 m, for instance soccer players 3.2 m, badminton, basketball and hockeyball players 1.6 m, and karate and tae-kwon-do practitioners 0.8 m, when testing agility skills [15]. It is likely that acceleration and

deceleration phases determine the agility performance more over shorter than longer distances. However, the reactive agility test only provides information on agility time (AT) which includes both reaction time (RT) and movement time (MT). From a practical perspective, estimating the contribution of these two components to the agility performance may provide additional relevant data for groups of athletes with diverse demands on decision-making and movement velocity. Such information on both reaction and movement times may be useful when designing training programs specifically focused on the improvement of weak components in agility performance. To address this issue, we estimated the contribution of simple reaction time, two-choice reaction time and step initiation velocity to the reactive agility time, while covering different distances in athletes of varied specializations.

Material and methods

Participants

Six groups of athletes volunteered to participate in the study (Table 1). They were required to be active in selected sports. They each had over 10 years' experience in particular sports with at least 7 years' experience in a competition. Those who met the inclusion criteria were allocated to the study. Approximately 77% of the athletes enrolled in the selected sports clubs participated. They were asked to avoid any strenuous exercise for the duration of the study. All participants were informed of the procedures and main purpose of the study. The procedures presented were in accordance with the ethical standards on human experimentation as stated in the Helsinki Declaration.

Experimental procedure

Prior to the study, participants attended a familiarization session during which the testing conditions were explained and trial sets carried out. Participants were encouraged to practice the measurement procedure beforehand in order to eliminate unfamiliarity with the exercise. Then they performed four tests in no particular order as follows:

In the Reaction Tests, participants were required to respond to either one visual stimulus (simple reaction

Table 1. Characteristics of groups of athletes (Mean \pm SD)

| Groups of athletes | <i>n</i> (1) | Age (years) | Height (cm) | Weight (kg) |
|-----------------------------|--------------|----------------|-----------------|----------------|
| Karate-kata practitioners | 14 | 20.3 \pm 2.2 | 171.8 \pm 4.6 | 64.5 \pm 7.9 |
| Karate-kumite practitioners | 22 | 21.5 \pm 3.6 | 174.5 \pm 7.3 | 70.3 \pm 6.5 |
| Hockeyball goalies | 6 | 23.8 \pm 3.5 | 177.7 \pm 5.7 | 74.9 \pm 6.7 |
| Hockeyball players | 17 | 22.8 \pm 3.1 | 178.6 \pm 6.4 | 72.6 \pm 5.7 |
| Soccer goalies | 9 | 24.1 \pm 4.7 | 178.1 \pm 6.3 | 76.0 \pm 7.7 |
| Soccer players | 27 | 21.9 \pm 2.9 | 174.6 \pm 5.1 | 69.5 \pm 6.3 |

Table 2. Protocols of the Reactive Agility Test

| Distance covered (m) | Number of stimuli (1) | Number of best responses used for analysis (1) | Groups of athletes |
|----------------------|-----------------------|--|---------------------------------------|
| 0.8 | 40 | 32 | karate-kata and -kumite practitioners |
| 1.6 | 20 | 16 | hockeyball players and goalies |
| 3.2 | 10 | 8 | soccer players and goalies |

time) or two visual stimuli in the form of a circle, square, triangle or cross (2-choice reaction time) positioned on mats on the floor. The mats had to be touched in accordance with the stimulus on the screen. Participants were instructed to keep their legs as close as possible to the mats in order to eliminate the influence of their leg movements on the outcome. They performed three trials of 40 responses in each test. Data from the best trial of simple RT and 2-choice RT were selected for analysis.

Reaction times were measured using a diagnostic system FiTRO Reaction Check (FiTRONiC, Slovakia) that consists of two mats connected by means of an interface to a computer. A special software measures the time the subject requires to accomplish leg contact with the mat corresponding to the stimulus on the screen. Software enables storage, analysis and extensive reporting of the data.

In the Step Initiation Test, participants performed voluntary steps in their own time. A device (described below) was anchored to the wall and tethered by a nylon rope to the ankle of the subject. The participant was instructed to perform, as quickly as possible, the steps while pulling the nylon tether of the device. Data from the best of 3 trials were utilised for analysis.

Movement velocity of the step was measured using the computer based system FiTRO Dyne Premium (FiTRONiC, Slovakia) that consists of a sensor unit based on a precise encoder mechanically coupled with a reel. While pulling the tether (connected to the ankle of the subject) the reel rotates and measures velocity. Signals from a sensor unit are conveyed to the computer by means of a USB cable. Comprehensive software allows the collection, calculation and on-line display of the basic biomechanical parameters involved in exercise. In this study, only maximal step velocity was utilised for analysis. Previous studies showed that intraclass correlation coefficient (ICC) was high for maximal step velocity and moderate for mean velocity in the acceleration phase as well as for maximal and mean acceleration [10]. In the same way, the standard error of measurement (SEM) was low for maximal step velocity and greater for the remaining parameters. Taking these findings into account, maximal velocity of the step initiation, as the most reliable parameter, was used for analysis in the present study.

In the Agility Test, participants were required to touch as fast as possible with either the left or the right foot

Table 3. Formula for calculation of the Agility Index

| Movement distance (m) | Agility Index calculation |
|-----------------------|---------------------------|
| 0.4 | $1 - (RT / AT)$ |
| 0.8 | $1 - [RT / (AT/1.3)]$ |
| 1.6 | $1 - [RT / (AT/1.9)]$ |
| 3.2 | $1 - [RT / (AT/3.1)]$ |

one of two mats located outside the two corners of a pre-defined square (Table 2). The mats had to be touched in accordance with the location of a stimulus in one of the corners of a screen. The test consisted of a pre-defined number of visual stimuli with random generation of their location on the screen, and the time of generation from 500 to 2500 ms, depending on the movement distance. The result was a sum of previously determined best agility times. In addition, the Agility Index (AI) was calculated as shown in Table 3. The Agility Index quantifies the relative contribution of movement time to the agility performance. The rest is attributed to change of direction running speed and anaerobic/aerobic capacity, when covering longer distances.

Agility time was measured by means of the computer based system FiTRO Agility Check (FiTRONiC, Slovakia). The system consists of contact switch mats connected by means of an interface to the computer. A special software measures the time required by the subject to establish foot contact with the mats, corresponding with the position of stimulus located in one of the four corners of the screen. Software enables storage of the data, their analyses and extensive reporting. The reliability of the test procedure was previously verified, and the testing protocol had been standardized by the examination of 196 participants [16]. The analysis of repeated measurements showed a measurement error of 7.1%, which is within range comparable to common motor tests.

The testing procedure and time of day were identical for all subjects. All tests were carried out mid-morning. The same experienced researchers conducted the measurements during testing sessions.

Data analysis

Data analysis was performed using the statistical program SPSS for Windows version 18.0 (SPSS, Inc., Chi-

ago, IL, USA). The calculation of the sample size was conducted with $\alpha = 0.05$ (5% change of type I error) and $1 - \beta = 0.80$ (power 80%) and using the results from our preliminary studies that identified variations in agility time between athletes of different sports. This provides a sample size of 16 for this study. However, the sample size in three groups was below this limit, as the inclusion criteria required participants to be active in a particular sport. Therefore, the statistical power for a group of size n ranged from 0.74 to 0.80. To compensate for the lower power and to estimate the magnitude of the differences across these groups, the effect size (ES) was calculated. Where statistical significance was not established, retrospective power calculations were performed to identify the power associated with the comparisons in question. Power calculations were performed on variables which showed a moderate effect size difference between these groups. The power for each level of comparison was calculated for a given difference between two mean values and the group sample sizes, and the standard deviation for each group mean. Sample sizes were calculated for each group, to provide the estimated sizes required to show a significant difference between groups in variables of simple RT, two-choice RT, maximal step velocity, and agility time.

One way analysis of variance (ANOVA) was used to estimate significant between-group differences in simple RT, two-choice RT, maximal step velocity, and agility time. The level for statistical significance was set at $p < 0.05$. Where the results of ANOVA indicated significant F-ratios between groups, the Scheffé test was applied *post hoc* to determine in which groups the differences occurred. Sex data, determined to be normally distributed, were analyzed in previous studies using the independent samples *t*-test and showed no significant differences in agility time between men and women. Nevertheless, only male athletes were selected for the present study. This was because longer movement distances were used in this study in comparison with the original version of the agility test, which could lead to different physiological responses and consequently affect the outcome in female and male athletes. Additionally, correlations between agility time and variables of simple RT, two-choice RT, and maximal step velocity were assessed by calculating Pearson's product moment (r). Data on reaction times, movement velocity, and agility time for all examined groups are presented as the mean \pm the standard deviation (SD).

Results

Results in karate-kata and karate-kumite practitioners are shown in Figures 1 a–d. Simple RT was significantly better in karate-kumite practitioners than in karate-kata ones (19.6%, $p = 0.006$; ES > 1.0). Two-choice RT was also significantly better in karate-kumite practitioners than in karate-kata ones (23.0%, $p =$

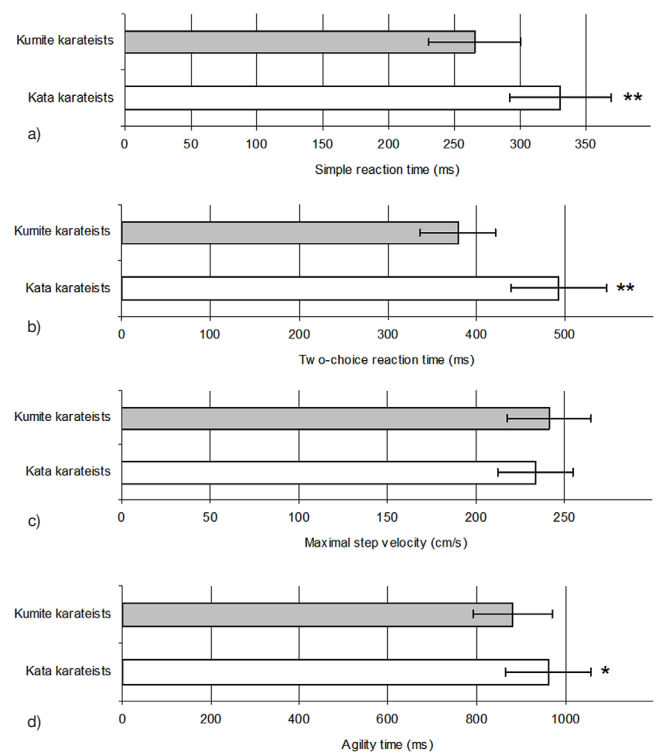


Figure 1. Simple reaction time (a), two-choice reaction time (b), maximal step velocity (c), and reactive agility time in karate-kumite and -kata practitioners (d) (* $p < 0.05$, ** $p < 0.01$)

0.003; ES > 1.0). Likewise, the agility time with a movement distance of 0.8 m between the subject and the mats was significantly better in karate-kumite practitioners than in karate-kata ones (8.2%, $p = 0.045$; ES = 0.85). However, maximal step velocity did not differ significantly between these groups (3.3%, $p = 0.233$; ES < 0.2).

Results in hockeyball goalies and players are shown in Figures 2 a–d. Goalies achieved significantly better values than players in both simple RT (7.9%, $p = 0.048$; ES = 0.75) and two-choice RT (10.3%, $p = 0.031$; ES = 0.93). On the other hand, agility time with a movement distance of 1.6 m between the subject and the mats was significantly better in players than in goalies (10.9%, $p = 0.028$; ES = 0.99). Also, maximal step velocity was significantly higher in players than in goalies (13.8%, $p = 0.017$; ES > 1.0).

Results in soccer goalies and players are shown in Figures 3 a–d. Goalies surpassed players in both simple RT (10.3%, $p = 0.034$; ES = 0.85) and two-choice RT (12.0%, $p = 0.024$; ES = 0.96). However, agility time with a movement distance of 3.2 m between the subject and the mats was significantly better in players than in goalies (14.2%, $p = 0.009$; ES > 1.0). The maximal step velocity was also significantly higher in players than in goalies (16.8%, $p = 0.007$; ES > 1.0).

Further analysis showed that simple RT, two-choice RT, and maximal step velocity were highly related to

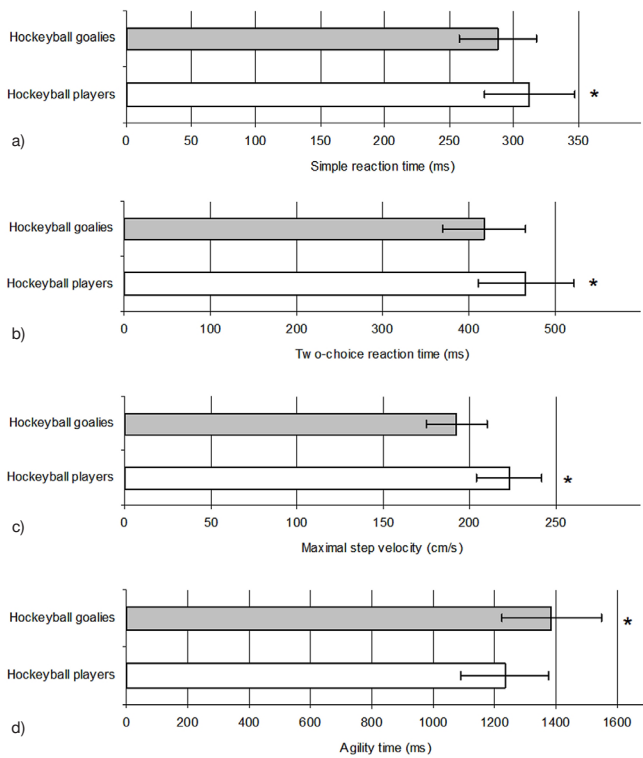


Figure 2. Simple reaction time (a), two-choice reaction time (b), maximal step velocity (c), and reactive agility time in hockeyball goalies and players (d) (* $p < 0.05$)

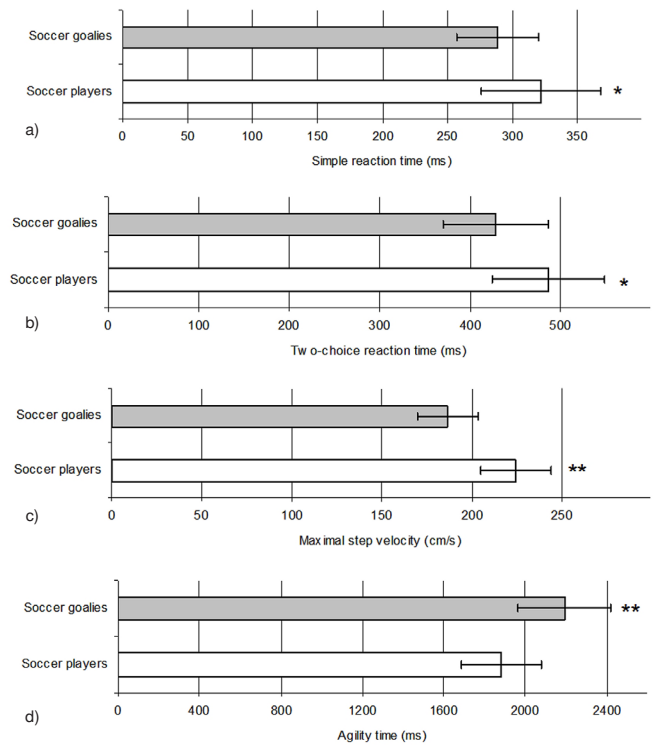


Figure 3. Simple reaction time (a), two-choice reaction time (b), maximal step velocity (c), and reactive agility time in soccer goalies and players (d) (* $p < 0.05$, ** $p < 0.01$)

agility time in the test with a shorter movement distance of 0.8 m ($r = 0.82, p < 0.01$; $r = 0.88, p < 0.01$; $r = 0.76, p < 0.05$). While simple RT and two-choice RT also strongly correlated with agility time in the test with longer movement distances of 1.6 m ($r = 0.76, p < 0.05$; $r = 0.72, p < 0.05$) and 3.2 m ($r = 0.79, p < 0.05$; $r = 0.75, p < 0.05$), there still remains considerable variation in the factors that contribute to performance over each movement distance. There were no significant relations of maximal step velocity to agility time in the tests with movement distances of 1.6 m ($r = 0.61$) and 3.2 m ($r = 0.52$). Therefore, other factors very likely contributed

to performance, namely change of direction running velocity and anaerobic/aerobic capacity, when responding to 20 stimuli over a distance of 1.6 m and 10 stimuli over a distance of 3.2 m.

These findings may be corroborated by a higher Agility Index found in karate-kumite than karate-kata practitioners (on average 0.442 and 0.335, respectively) (Figure 4a). Similarly, a higher Agility Index was identified in hockeyball and soccer goalies (on average 0.427 and 0.394, respectively) than in hockeyball and soccer players (on average 0.283 and 0.199, respectively) (Figure 4b).

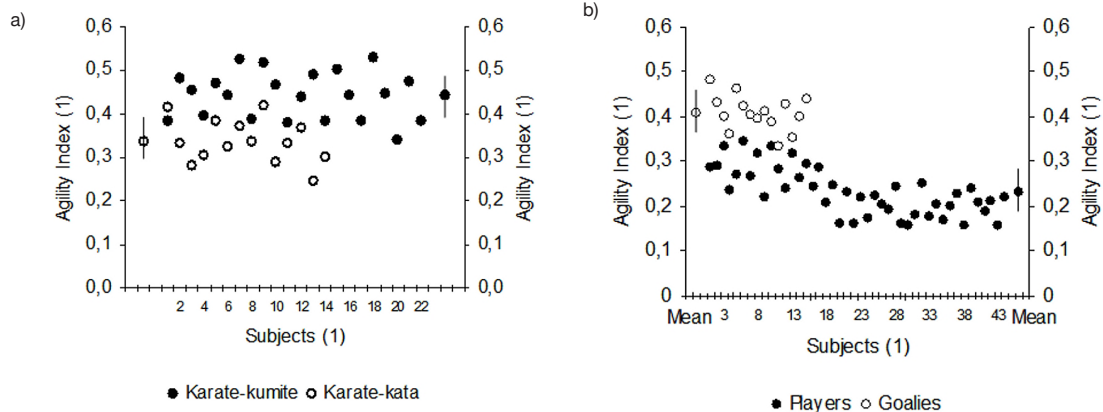


Figure 4. The Agility Index in karate-kumite and karate-kata practitioners (a) and players and goalies of hockeyball and soccer (b)

Discussion

Although covering the same total distance, the protocols used in the present study involved more multiple direction changes over a short distance (40×0.8 m) compared to those designed for longer distances (20×1.6 m and 10×3.2 m). Results confirmed our assumption that the strength of the associations between maximal step velocity and agility time decrease when the later is measured over longer distances. Relative speed of the first acceleration step appears to be an important component in determining change of direction ability over short distances [14]. This is consistent with previous studies that reported acceleration as an important aspect in agility and change of direction movement [2, 17–19]. However, the ability to decelerate CoM rapidly is also a key component of change of direction ability [14]. When undertaking a 180° change of direction test, deceleration movement times are extremely variable within and between individuals, particularly when compared with acceleration movement times [14]. Accordingly, the change of direction tests evaluate an athlete's ability to rapidly decelerate and reaccelerate in the new direction. When longer distances are covered, the total running time contains both change of direction ability and straight-line sprinting. In addition to this, agility tests include also perceptual and decision making components. Thus, breaking down the agility performance into two distinct phases is warranted. Recently, Sekulic et al. [20] reported that calculating stop'n'go change of direction speed to stop'n'go reactive-agility test ratio may allow strength and conditioning coaches to indirectly determine the perceptual and reaction capacities of their athletes. In the present study, higher Agility Indexes indicate the use of both sensory and motor components in athlete's performance, whereas their lower values signify the predominant contribution of motor abilities to agility performance. On the basis of our research, players may require varied agility skill training utilising motor abilities rather than sensory functions, as the longer distances appear more reliant on change of direction running velocity and anaerobic/aerobic capabilities. On the other hand, our results also identified the importance of cognitive factors in reactive agility performance for goalies and karate-kumite practitioners and suggest that specific methods may be required for training and testing of reactive agility and change of direction speed.

Taking into account the competition area in karate, the distance of 0.8 m between contact mats was used for the agility test, which identified better simple and two-choice reaction times in karate-kumite than the karate-kata practitioners. This very likely contributed to enhanced agility performance, as there were no significant differences in movement velocity between these groups. The contribution of movement time to the agility time was 33.5% in karate-kata practitioners and 44.2% in karate-kumite ones.

These results are in accordance with previous findings, in which individual differences in each component of the Agility Test were estimated [21]. In subject 1, multi-choice reaction time accounted for 64% of the agility time. However, in subject 2, multi-choice reaction time accounted for only 43% of the agility time. Interestingly, subject 1, with both longer simple and multi-choice reaction times, was able to achieve better agility times than subject 2. This was probably due to the fact that the participant initiated his/her foot responses more rapidly than his/her counterparts. This individual was in fact an elite karate-kata competitor, who does not respond to any stimuli but must be able to cover a short distance very quickly. Thus, it may be assumed that this result reflects a sport-specific adaptation. In contrast, despite better simple and multi-choice reaction times in subject 2, he/she was not able to transfer this capability into improved agility performance. These findings indicate that individual differences in agility time (RT + MT) are greater (about 26%) than in simple and multi-choice reaction times (18% and 9%, respectively).

In the present study, faster simple and two-choice reactions were found in hockeyball goalies than players when covering a distance of 1.6 m and in soccer goalies than players when covering a longer distance of 3.2 m. In contrast, higher maximal step velocity was recorded in hockeyball players than goalies. These differences were even more pronounced between soccer players and goalies. Higher movement time most likely contributed to better agility time in both hockeyball and soccer players than goalies. The contribution of movement time to the agility time was lower in players of hockeyball (28.3%) and soccer (19.9%) than goalies of hockeyball (42.7%) and soccer (39.4%).

Similarly, the changes in each component of agility performance following exercise or long-term systematic training can be evaluated. One study evaluated the effect of soccer match induced fatigue on neuromuscular performance [22]. After the first 45 min of the game, only dynamic balance with eyes closed was impaired, and ground contact time increased. A further increase was observed after the second period of the game. Along with dynamic balance with eyes open, agility performance (in the test with shorter – 0.8 m distance between mats) was also affected. On the other hand, there were no significant pre-post match changes in static balance, agility time (in the test with longer – 1.5 m distance between mats), speed of the step initiation and the soccer kick, height of the squat and countermovement jump. These findings indicate that fatigue impairs cognitive functions more than motor functions in highly skilled soccer players.

Another study compared the effect of 6 weeks of training consisting of reaction tasks similar to game situations on wobble boards (experimental group 1) and on a stable surface (experimental group 2) on neuromus-

cular performance in basketball players [23]. Following the training, there were no significant changes in simple and multi-choice reaction times when fingers were close to the buttons. However, a significantly shorter agility time was identified when subjects were required to move to the contact mats. Maximal velocity of step initiation also significantly improved after the training. This faster movement execution most probably contributed to the enhancement of agility performance. This assumption was corroborated by a significant correlation ($r = 0.78$) between the reduction in agility time and an increase in maximal velocity of step initiation after the training. Also of interest was the additional finding that the improvement in agility performance in older players (21 years on average) was greater than in their younger, less experienced counterparts (15 years on average). These results may be attributed to more rapid feedback control of movement execution, i.e. as the experience level increased with practice, the movement time decreased.

These findings indicate that assessment of simple and multi-choice reaction times, as well as movement time or movement velocity may provide additional information on individual differences in sensory and motor contribution to the agility performance. This would enhance differentiation of athletes with varied demands on agility skills, plus improve the evaluation of the efficiency of agility training.

Conclusions

The present study highlighted differential contributions of reaction time and step velocity to the agility time, depending upon a movement distance. It appears that cognitive and motor skills are better in karate-kumite than karate-kata practitioners, when only stepping reactions are required. In the case of longer distances, better agility time was found in players than in goalies of soccer and hockeyball. While the motor component of agility performance seems to be predominant in players in terms of faster movement execution, in goalies it is the sensory component allowing faster decision making. Hence, the agility test complemented with measurements of simple and multi-choice reaction times, and movement time or movement velocity provides additional information on agility performance in athletes with diverse demands on their agility skills. This differential contribution of reaction time and movement velocity to the agility performance should be addressed in agility testing in order to identify an athlete's weakness.

Acknowledgments

This work was supported by the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences (No. 1/0373/14).

References

1. Sheppard J.M., Young W.B., Doyle T.L., Sheppard T.A., Newton R.U., An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *J Sci Med Sport*, 2006, 9 (4), 342–349, doi: 10.1016/j.jsams.2006.05.019.
2. Sheppard J.M., Young W.B., Agility literature review: classifications, training and testing. *J Sports Sci*, 2006, 24 (9), 919–932, doi: 10.1080/02640410500457109.
3. Schmidt R.A., Wrisberg C.A., Motor learning and performance. Human Kinetics, Champaign 2004.
4. Young W.B., Willey B., Analysis of a reactive agility field test. *J Sci Med Sport*, 2010, 13 (3), 376–378, doi: 10.1016/j.jsams.2009.05.006.
5. Farrow D., Young W., Bruce L., The development of a test of reactive agility for netball: a new methodology. *J Sci Med Sport*, 2005, 8 (1), 52–60. Available from: https://www.researchgate.net/profile/Warren_Young/publication/7853177_The_Development_of_a_Test_of_Reactive_Agility_for_Netball_A_New_Methodology/links/02e7e529cf9deeb175000000.pdf.
6. Gabbett T., Benton D., Reactive agility of rugby league players. *J Sci Med Sport*, 2009, 12 (1), 212–214, doi: 10.1016/j.jsams.2007.08.011.
7. Serpell B.G., Ford M., Young W.B., The development of a new test of agility for rugby league. *J Strength Cond Res*, 2010, 24(12), 3270–3277, doi: 10.1519/JSC.0b013e3181b60430.
8. Paul D.J., Gabbett T.J., Nassis G.P., Agility in team sports: testing, training and factors affecting performance. *Sports Med*, 2016, 46 (3), 421–442, doi: 10.1007/s40279-015-0428-2.
9. Zemková E., Tirpáková V., Miklovič P., Hamar D., Reliability and methodological issues of the visually-triggered step initiation test. In: Proceedings of the XVIII Congress of the International Society of Electrophysiology and Kinesiology. ISEK, Aalborg 2010, 110.
10. Zemková E., Hamar D., Lipková J., Speed of step initiation in physically active and sedentary subjects of different age. *Acta Fac Educ Phys Univ Comenianae*, 2013, LIII (1), 5–13.
11. Little T., Williams A.G., Specificity of acceleration, maximum speed, and agility in professional soccer players. *J Strength Cond Res*, 2005, 19 (1), 76–78, doi: 10.1519/14253.1.
12. Mayhew J.L., Piper F.C., Schwegler T.M., Ball T.E., Contributions of speed, agility and body composition to anaerobic power measurement in college football players. *J Strength Cond Res*, 1989, 3, 101–106.
13. Young W., Hawken M., McDonald L., Relationship between speed, agility and strength qualities in Australian Rules football. *Strength Cond Coach*, 1996, 4 (4), 3–6.
14. Sayers M.G., Influence of test distance on change of direction speed test results. *J Strength Cond Res*, 2015, 29 (9), 2412–2416. doi: 10.1519/JSC.0000000000001045.
15. Zemková E., Hamar D., Assessment of agility performance under sport-specific conditions. *AJESS*, 2013, 10 (1), 47–60. Available from: https://www.researchgate.net/profile/Erika_Zemkova/publication/248707069_Assessment_of_Agility_Performance_Under_Sport-Specific_Conditions/links/02e7e51e115216fa48000000.pdf.
16. Zemková E., Hamar D., Test of disjunctive reaction-speed abilities of lower limbs [In Slovak]. In: Proceedings of the scientific conference. Palacký University, Olomouc 1998, 178–181.

17. Young W.B., McDowell M.H., Scarlett B.J., Specificity of sprint and agility training methods. *J Strength Cond Res*, 2001, 15 (3), 315–319. Available from: https://www.researchgate.net/profile/Warren_Young/publication/11643863_Specificity_of_Sprint_and_Agility_Training_Methods/links/0c9605182eb811907a000000.pdf.
18. Pyne D., Simple fitness testing for individual and team sports. Part 2: Speed, agility, and strength. *Sports Coach*, 2002, 24, 10–11.
19. Spiteri T., Cochrane J.L., Hart N.H., Haff G.G., Nimphius S., Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci*, 2013, 13(6), 646–652, doi:10.1080/17461391.2013.774053.
20. Sekulic D., Krolo A., Spasic M., Uljevic O., Peric M., The development of a new stop'n'go reactive-agility test. *J Strength Cond Res*, 2014, 28 (11), 3306–3312, doi: 10.1519/JSC.0000000000000515.
21. Zemková E., Hamar D., Toward an understanding of agility performance. Albert, Boskovic 2009.
22. Zemková E., Hamar D., The effect of soccer match induced fatigue on neuromuscular performance. *Kinesiology*, 2009, 41 (2), 195–202. Available from: https://www.researchgate.net/profile/Erika_Zemkova/publication/245334311_THE_EFFECT_OF_SOCCER_MATCH_INDUCED_FATIGUE_ON_NEUROMUSCULAR_PERFORMANCE/links/0deec51d70ad49a6dc000000.pdf.
23. Zemková E., Hamar D., The effect of 6-week of combined agility-balance training on neuromuscular performance in basketball players. *J Sports Med Phys Fitness*, 2010, 50 (3), 262–267.

Paper received by the Editor: March 25, 2016

Paper accepted for publication: May 25, 2016

Correspondence address

Erika Zemková

Department of Sports Kinanthropology

Faculty of Physical Education and Sports

Comenius University in Bratislava

Nábr. arm. gen. L. Svobodu 9

814 69 Bratislava, Slovakia

e-mail: erika.zemkova@uniba.sk