Design and evaluation of specific tests, factors of success and efficiency of training programs for the development of agility in tennis

Sinković, Filip

University of Zagreb

FACULTY OF KINESIOLOGY

Filip Sinković

DESIGN AND EVALUATION OF SPECIFIC TESTS, FACTORS OF SUCCESS AND EFFICIENCY OF TRAINING PROGRAMS FOR THE DEVELOPMENT OF AGILITY IN TENNIS

DOCTORAL THESIS

Zagreb, 2024

Sveučilište u Zagrebu

KINEZIOLOŠKI FAKULTET

Filip Sinković

OBLIKOVANJE I VREDNOVANJE SPECIFIČNIH TESTOVA, ČIMBENICI USPJEŠNOSTI I UČINKOVITOST TRENAŽNIH PROGRAMA ZA RAZVOJ AGILNOSTI U TENISU

DOKTORSKI RAD

Zagreb, 2024

University of Zagreb

FACULTY OF KINESIOLOGY

Filip Sinković

DESIGN AND EVALUATION OF SPECIFIC TESTS, FACTORS OF SUCCESS AND EFFICIENCY OF TRAINING PROGRAMS FOR THE DEVELOPMENT OF AGILITY IN TENNIS

DOCTORAL THESIS

Supervisor:

Assistant Professor Dario Novak, PhD

Zagreb, 2024

Sveučilište u Zagrebu

KINEZIOLOŠKI FAKULTET

Filip Sinković

OBLIKOVANJE I VREDNOVANJE SPECIFIČNIH TESTOVA, ČIMBENICI USPJEŠNOSTI I UČINKOVITOST TRENAŽNIH PROGRAMA ZA RAZVOJ AGILNOSTI U TENISU

DOKTORSKI RAD

Mentor:

doc.dr.sc. Dario Novak

Zagreb, 2024

SUPERVISOR INFORMATION

Dr. Dario Novak is an associate professor at the University of Zagreb, Croatia. He received his Ph.D. in sports science from University of Zagreb in 2010. He was a postdoctoral fellow of Columbia University, New York and Harvard University, Boston, US. Doctor Novak's research interests lie in integrated and holistic approaches in the field of human health and performance. An editor of one book and author of over 200 publications in scientific and sports journals, Doctor Novak has offered several keynotes and invited presentations, and over 100 conference paper presentations. He has received both the FIEP Europe Thulin Award 2011 from the International Federation of Physical Education (FIEP Europe) and International FIEP Cross of Honor Award from the International Federation of Physical Education (FIEP World). In 2017 was recognized by the FIEP Mexico at Mexico City where he has received the Medalla Prof. Adolfo Pérez Acosta as an outstanding scholar for his contributions to educational research. In addition, he was the recipient of the 2015, 2016 and 2017 University of Zagreb, Faculty of Kinesiology, Best Young Scientists Award. In 2018 the National Science Awards Committee, formed by the Croatian Parliament, has selected Doctor Novak for precious Annual Award for Junior Researcher. It is granted to the outstanding young scientists in recognition of their scientific and research activities. In 2019 he received the Ambassador of Physical Education Award for human health and performance promotion. In 2020 he received the National PE Award from the Croatian Kinesiology Federation. He was part of Donna Vekic's coaching team for almost 10 years (best ranking #21 in the world WTA), Christina McHale's coaching team (best ranking #24 in the world WTA) as well as part of Marta Kostyuk's coaching team (#2 in the world in ITF Juniors and 2017 Australian Open girls' singles championships) and Elena Rybakina's coaching team (Wimbledon Champion in 2022). Currently, he is part of Stan Wawrinka's coaching team (3 times Grand Slam Champion). In the past Dr. Novak has also worked with Borna Coric (#1 in the world in ITF Juniors) and Ivana Jorovic (#1 in the world in ITF Juniors) among many others. He worked as a consultant with a number of teams and organizations including Bosnia and Herzegovina national basketball team.

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor, Dario Novak, for dedicating his time and effort as the mentor of this project, and for providing me with advice and guidance throughout my research. With a friendly approach, patience, kindness, and knowledge, I am grateful that he set my first scientific steps. Also, I would like to thank my coauthors and colleagues, Nikola Foretić, Erika Zemková, Petar Barbaros and Zlatan Bilić for their assistance in writing, analyzing, and discussing the research results that are now part of this doctoral thesis.

I am also grateful to all the young tennis players, their parents, and coaches who dedicated their time to participate in the study, showing great determination and effort during training and testing. I would like to thank all the volunteers and measurers who greatly contributed to the quality of this dissertation through their hard work.

Furthermore, I would like to thank my family, friends, and tennis colleagues, who have always been there for me when I needed help, and whose support has been a great source of motivation.

Finally, I owe the greatest thanks to my parents, Ivanka and Ivan, without whom none of this would have been possible. They have provided me with support in every sense of the word, and their sacrifice, help, and faith in my success have been with me throughout my entire educational journey. I hope that I have made you proud.

Filip

LIST OF ABBREVIATIONS:

BMI – body mass index

CA – Cronbach alpha

CV – coefficient of variation

CODS – change of direction speed

ICC – intraclass correlation coefficient

RAG – reactive agility

SSC – stretch-shortening cycle

TAT – tennis agility test

TENCODS – change of direction speed test

TENRAG – reactive agility test

TS-RAN – tennis-specific reactive agility test

WS – Witty SEM

Table of contents

ABSTRACT

Aim The main aim of the doctoral thesis is to design and evaluate specific tests, explore the correlation between anthropometric variables and motor abilities and assess the efficiency of training programs for the development of agility in tennis. Three specific goals were set for three studies (Study 1, Study 2 and Study 3). Study 1 aimed to develop and validate a new test for assessing change of direction speed and reactive agility. Study 2 aimed to investigate the correlation between anthropometric variables and motor abilities with change of direction speed and reactive agility performance in young tennis players. Study 3 aimed to determine the effect of a six-week plyometric training program on sport-specific motor abilities, change of direction speed and reactive agility.

Study 1 methods 50 male tennis players (age 12.3 ± 1.2 years, height 156.7 ± 12.8 cm, body mass 45.9 ± 8.9 kg) who were ranked up to 50th place in the ranking of the National Tennis Association, as well as up to 300th place on the international "Tennis Europe" ranking, participated in the study. Change of direction speed and reactive agility variables were measured using newly constructed change of direction speed test (TENCODS) and reactive agility test (TENRAG), which were designed to mimic specific movements in tennis.

Study 1 results It can be concluded that the newly constructed tests of change of direction speed and reactive agility have a moderate to good degree of reliability. Additionally, the assumption that the reliability will be slightly higher for change of direction speed tests (CA = 0.92 and 0.92; ICC = 0.86 and 0.82) than for reactive agility tests (CA = 0.90 and 0.89; ICC = 0.74 and 0.72) was proven to be accurate. The results also showed that the tests have acceptable validity. Thus, the results of both tests show a moderate to large correlation (p = 0.6 and p = 0.55) with the T-TEST of agility. It can be noted that all measurements, that is, all results, are normally distributed and that the values of skewness and kurtosis are within acceptable limits. Based on the obtained skewness and kurtosis values, it can be concluded that there is acceptable sensitivity and applicability to the sample of young tennis players.

Study 1 conclusion This research confirmed the hypothesis and showed that the newly constructed change of direction speed and reactive agility tests have acceptable metric characteristics. Thus, this paper proposed a new procedure for the assessment of pre-planned

and reactive agility in young tennis players, which will significantly improve and advance the existing procedures.

Study 2 methods 50 male tennis players (age 12.3 ± 1.2 years, height 156.7 ± 12.8 cm, body mass 45.9 ± 8.9 kg) who were ranked up to 50th place in the ranking of the National Tennis Association, as well as up to 300th place on the international "Tennis Europe" ranking, participated in the study. The sample of anthropometric variables in this study included the measurement of participant height, body mass, body mass index and percentage of body fat. Additionally, participants performed tests to assess speed (5, 10 and 20-meter sprints), change of direction speed (20 yards, 4x10 yards, T-TEST, TENCODS), reactive agility (TENRAG) and explosive power (countermovement jump, single-leg countermovement jump, squat jump, standing long jump and single-leg triple jump).

Study 2 results The results showed that there is a statistically significant correlation ($p < 0.05$) between change of direction speed and reactive agility with anthropometric characteristics ($r = -0.30$ to -0.41), running speed tests ($r = 0.33$ to 0.51) and horizontal explosive power variables ($r = -0.37$ to -0.49), but there was no significant correlation ($p > 0.05$) observed with vertical explosive power variables ($r = -0.03$ to -0.27). However, based on the obtained results, it can be noticed that the correlations marked as significant are not extremely large, ranging within 0.30 – 0.63, indicating a moderate correlation. More specifically, the largest correlation ($r = 0.47$ to 0.61) was obtained between change of direction speed tests (20 yards, 4x10 yards, T–TEST), which is logical since they are constructed in a similar way to TENCODS and TENRAG, containing similar movement patterns. Also, the 20 m sprint time ($r = 0.51$) falls within the range of the highest correlation.

Study 2 conclusion In conclusion, the results of this research confirmed the hypothesis that there is a significant correlation between anthropometric variables and motor abilities with change of direction speed and reactive agility performance among young tennis players. These findings provide valuable information for coaches to design a variety of tennis-specific exercises aimed at enhancing performance, particularly in terms of players' neuromuscular fitness.

Study 3 methods The participants in this study included 35 male tennis players (age 12.14 ± 1.3 years, height 157.35 ± 9.53 cm and body mass 45.84 ± 8.43 kg at the beginning of the experiment). 18 of the participants were randomly assigned to the control group, and 17 were assigned to the experimental group. Running speed (sprints at 5, 10, and 20 meters), change of direction speed (4x10 yards, 20 yards, T-test, TENCODS), reactive agility (TENRAG), and explosive power (long jump, single leg triple jump, countermovement jump, squat jump, and single leg countermovement jump) were all tested. The Mixed model (2x2) ANOVA was used to determine the interactions and influence of a training program on test results. Furthermore, Bonferroni post hoc test was performed on variables with significant time*group interactions.

Study 3 results The results of this research indicate that an experimental training program affected results in a set time period, i.e. 5 out of total 15 variables showed significant improvement after experimental protocol when final testing was conducted. The experimental group showed significantly improved results in the 5m sprint test (6.3%) in the final testing phase compared to the initial testing phase, this was also the case in comparison to the control group in both measurements. Furthermore, the experimental group showed significant improvement in the single leg countermovement jump (16.1% and 20.2%) in the final test, as well as in comparison to the control group in both measurements. The change of direction speed and reactive agility test also exhibited significant improvement (5.9% and 6.0%) in the final testing phase of the experimental group.

Study 3 conclusion The results of this research indicated that a six-week program dominated by plyometric training can have a significant effect on the improvement of specific motor abilities within younger competitive categories. These results offer valuable insights for coaches in designing diverse tennis-specific scenarios to enhance overall performance, particularly focusing on the neuromuscular fitness of their players.

Key words: reliability, validity, correlation, motor abilities, plyometrics, neuromuscular training

SAŽETAK

Cilj Glavni cilj ove doktorske disertacije je oblikovanje i vrednovanje specifičnih testova, istraživanje korelacija između antropometrijskih varijabli i motoričkih sposobnosti te evaluacija učinkovitosti trenažnih programa za razvoj agilnosti u tenisu. Tri specifična cilja postavljena su za tri studije (Studija 1, Studija 2 i Studija 3). Studija 1 imala je za cilj validaciju novokonstruiranog testa za procjenu specifične teniske brzine promjene smjera kretanja i reaktivne agilnosti. Studija 2 imala je za cilj utvrditi povezanost antropometrijskih karakteristika i motoričkih sposobnosti (brzine trčanja i eksplozivne snage) s brzinom promjene smjera kretanja i reaktivnom agilnosti kod mladih tenisača. Studija 3 imala je za cilj utvrditi utjecaj šestotjednog pliometrijskog treninga na brzinu promjene smjera kretanja i reaktivnu agilnost.

Studija 1 metode Uzorak ispitanika obuhvatio je 50 mladih natjecatelja (dobi 12.34 ± 1.22 godina, visine 156.7 ± 12.8 cm, mase 45.9 ± 8.9 kg) koji su rangirani na ljestvici nacionalnog teniskog saveza do 50 mjesta kao i na međunarodnoj „Tennis Europe“ ljestvici do 300 mjesta. Varijable brzine promjene smjera kretanja i reaktivne agilnosti mjerile su se novokonstruiranim TENCODS i TENRAG testovima koji su konstruirani na način da ispitanici oponašaju specifične kretnje u tenisu.

Studija 1 rezultati Na temelju dobivenih rezultata može se zaključiti kako novokonstruirani testovi brzine promjene smjera kretanja i reaktivne agilnosti imaju umjereni stupanj pouzdanosti. Također, potvrdila se pretpostavka da će pouzdanost biti neznatno veća za testove brzine promjene smjera kretanja (CA = 0.92 i 0.92; ICC = 0.86 i 0.82) nego za testove reaktivne agilnosti (CA = 0.90 i 0.89; ICC = 0.74 i 0.72). Također, rezultati su pokazali kako testovi imaju zadovoljavajuću valjanost. Tako rezultati oba testa pokazuju umjerenu povezanost (p = 0.6 i p = 0.55) s T-TESTOM agilnosti. Po dobivenim rezultatima može se primijetiti da su sve čestice mjerenja, odnosno svi rezultati normalno distribuirani te da se vrijednosti Skewnessa i Kurtosisa kreću u granicama prihvatljivosti. Na temelju dobivenih vrijednosti, može se zaključiti da postoji zadovoljavajuća osjetljivost i primjenjivost na uzorku mladih tenisača.

Studija 1 zaključak Ovo istraživanje je potvrdilo postavljenu hipotezu te su rezultati pokazali kako novokonstruirani testovi brzine promjene smjera kretanja i reaktivne agilnosti

posjeduju zadovoljavajuće metrijske karakteristike, posebice reaktivni test agilnosti. Tako se ovim radom predložio novi postupak za procjenu brzine promjene smjera kretanja i reaktivne agilnosti kod mladih tenisača čime će se značajno poboljšati i unaprijediti postojeći postupci.

Studija 2 metode Uzorak ispitanika obuhvatio je 50 mladih natjecatelja (dobi 12.34 ± 1.22 godina, visine 156.7 ± 12.8 cm, mase 45.9 ± 8.9 kg) koji su rangirani na ljestvici nacionalnog teniskog saveza do 50 mjesta kao i na međunarodnoj „Tennis Europe“ ljestvici do 300 mjesta. Uzorak antropometrijskih varijabli sastojao se od tjelesne visine, tjelesna mase, indeksa tjelesne mase i postotka masti. Također, mjerili su se testovi za procjenu brzine trčanja (sprint na 5, 10 i 20 metara), brzine promjene smjera kretanja (20 jardi, 4x10 jardi, T-TEST, TENCODS), reaktivne agilnosti (TENRAG) i eksplozivne snage (skok s pripremom, jednonožni skok s pripremom, skok iz čučnja, skok u dalj s mjesta i jednonožni troskok s mjesta).

Studija 2 rezultati Dobiveni rezultati pokazali su da postoji statistički značajna korelacija ($p < 0.05$) između brzine promjene smjera kretanja i reaktivne agilnosti s antropometrijskim karakteristikama ($r = -0.30$ do -0.41), testovima brzine trčanja ($r = 0.33$ do 0.51) i varijablama horizontalne eksplozivne snage ($r = -0.37$ do -0.49), dok korelacija s varijablama vertikalne eksplozivne snage ($r = -0.03$ do -0.27) nije statistički značajna ($p > 0.05$). Međutim, na temelju dobivenih rezultata može se primijetiti da korelacije koje su označene kao značajne nisu izrazito velike, krećući se u rasponu od 0.30 – 0.63, što ukazuje na umjerenu korelaciju. Konkretnije, najveća korelacija ($r = 0.47 - 0.61$) dobivena je između testova brzine promjene smjera (20 jardi, 4x10 jardi, T–TEST), što je logično s obzirom da su konstruirani na sličan način kao TENCODS i TENRAG, odnosno sadrže slične obrasce kretanja. Također, vrijeme sprinta na 20 metara ($r = 0.51$) nalazi se unutar raspona najveće korelacije.

Studija 2 zaključak Ovim se istraživanjem potvrdila hipoteza i pokazalo da postoji značajna korelacija gotovo svih antropometrijskih varijabli i motoričkih sposobnosti s brzinom promjene smjera kretanja i reaktivnom agilnosti kod mladih tenisača. S toga, ove spoznaje pružaju korisne informacije trenerima za stvaranje širokog spektra situacija specifičnih za tenis kako bi razvili odgovarajuću metode za poboljšanje živčano-mišićnih sposobnosti svojih igrača.

Studija 3 metode Uzorak ispitanika obuhvatio je 35 mladih natjecatelja (dobi 12.34 ± 1.22 godina, visine 156.7 ± 12.8 cm, mase 45.9 ± 8.9 kg na početku istraživanja) koji su rangirani na ljestvici nacionalnog teniskog saveza do 50 mjesta kao i na međunarodnoj „Tennis Europe“ ljestvici do 300 mjesta. 18 ispitanika nasumičnim je odabirom raspoređeno u kontrolnu grupu dok je 17 ispitanika raspoređeno u eksperimentalnu grupu. mjerili su se testovi za procjenu brzine trčanja (sprint na 5, 10 i 20 metara), brzine promjene smjera kretanja (20 jardi, 4x10 jardi, T-TEST, TENCODS), reaktivne agilnosti (TENRAG) i eksplozivne snage (skok s pripremom, jednonožni skok s pripremom, skok iz čučnja, skok u dalj s mjesta i jednonožni troskok s mjesta). Mješoviti model (2x2) ANOVA korišten je za određivanje interakcija i utjecaja programa treninga na rezultate testa. Nadalje, Bonferronijev post hoc test proveden je na varijablama sa značajnim vrijeme*grupa interakcijama.

Studija 3 rezultati Rezultati ovog istraživanja pokazali su kako je eksperimentalni program treninga utjecao na rezultate u zadanom vremenskom razdoblju, tj. 5 od ukupno 15 varijabli pokazalo je značajno poboljšanje kada je provedeno finalno testiranje. Eksperimentalna grupa pokazala je značajno bolje rezultate (6.3%) u testu sprinta na 5m u završnoj fazi testiranja u odnosu na početnu fazu testiranja, a to je bio slučaj i u usporedbi s kontrolnom grupom u oba mjerenja. Nadalje, eksperimentalna grupa pokazala je značajan napredak (16.1% i 20.2%) u jednonožnom skoku s pripremom u završnom testu, kao i u usporedbi s kontrolnom skupinom u oba mjerenja. Testovi brzine promjene smjera kretanja i reaktivne agilnosti također su pokazali značajan napredak (5.9% i 6.0%) u završnoj fazi testiranja eksperimentalne grupe.

Studija 3 zaključak Ovo istraživanje je pokazalo kako šestotjedni program koji je dominantno baziran na pliometrijskom treningu može značajno poboljšati specifične motoričke sposobnosti s naglaskom na brzinu promjene smjera kretanja i reaktivnu agilnost kod mlađih natjecateljskih kategorija tenisača. Dobivene spoznaje pružaju korisne informacije trenerima za stvaranje širokog spektra situacija specifičnih za tenis kako bi razvili odgovarajuću metode za poboljšanje živčano-mišićnih sposobnosti svojih igrača.

Ključne riječi: pouzdanost, valjanost, korelacija, motoričke sposobnosti, pliometrija, neuromišićni trening

THESIS OUTLINE

This thesis consists of four chapters. Chapter one covers a general introduction to the scientific problem through a literature review and defines research aims and questions. Chapter two presents the published articles included in this thesis. The first study (Study 1) aims to develop and validate a new test for assessing change of direction speed and reactive agility. The second study (Study 2) aims to investigate the correlation between anthropometric variables and motor abilities with change of direction speed and reactive agility performance in young tennis players. The third study (Study 3) attempts to determine the effect of a six-week plyometric training program on motor abilities, change of direction speed and reactive agility. Chapter three provides a discussion about the published articles. Chapter four offers a general conclusion for all three presented studies, along with the limitations and perspectives for future research.

INTRODUCTION

Context and literature review

Monitoring the agility performance of talented youth tennis players is expected to provide valuable insights into the development of their skills (Kramer, Huijgen, Elferink-Gemser and Visscher, 2017). Minimizing errors during data collection is highly important in any research procedure (Atkinson and Nevill, 1998). This emphasizes the importance of understanding measurement theory as well as the two most valuable criteria for assessing quality: reliability and validity. Reliability is directly related to the error component of the score; the larger the error, the lower the reliability (Currell and Jeukendrup, 2008). The reliability and variation of the results are particularly important, especially in training studies when it is essential to determine whether the exercises performed result in a real and meaningful change in the measured variable (Brughelli, Cronin, Levin and Chaouachi, 2008). Moreover, the reliability of a test's performance pertains to how consistent and reproducible the results are when the same test is conducted multiple times. If a test exhibits poor reliability, it is unsuitable for monitoring changes in performance over trials and lacks precision in assessing performance in a single attempt (Hopkins, 2000; Hopkins, Marshall, Batterham and Hanin, 2009).

There are numerous statistical procedures used in the estimation of reliability, and they can all be categorized into one of two types of reliability: relative reliability and absolute reliability (Atkinson and Nevill, 1998; Baumgartner and Chung 2001; Hopkins, 2000; Weir, 2005). Relative reliability assesses the strength of the connection between repeated measurements by quantifying the correlation between these repeated measures. On the other hand, absolute reliability pertains to the variability of scores from trial to trial (within subjects or measurements) and is not influenced by the sample, as it does not account for the range of individual scores (Hopkins, Schabort, and Hawley, 2001; Currell and Jeukendrup, 2008).

The most commonly used measure for relative reliability is the intraclass correlation coefficient (ICC), while the coefficient of variation (CV) is utilized for absolute reliability. ICC is a reliability index that reflects both the degree of correlation and agreement between measurements. It has been widely used to evaluate the interrater and test-retest reliability of numerical or continuous measurements (Koo and Li, 2016). There are different forms of ICC that can yield varying results when applied to the same set of data, and the ways researchers report ICC may differ. Since different forms of ICC involve distinct assumptions in their calculations and can lead to different interpretations, it is essential for researchers to be aware of the correct application of each form of ICC, use the appropriate form in their analyses, and accurately report the form they used (Koo and Li, 2016).

It's important to emphasize that there is no consensus on standard values for acceptable reliability using ICC. A low ICC may not only reflect a low degree of rater or measurement agreement but could also be related to the lack of variability among the sampled subjects, the small number of subjects, and the small number of raters being tested (Portney and Watkins, 2009; Lee et al., 2012). In line with that, Koo and Li (2016) suggest that ICC values less than 0.5 indicate poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability. It is logical to determine the level of reliability (i.e., poor, moderate, good, and excellent) by testing whether the obtained ICC value significantly exceeds the suggested values mentioned above using statistical inference (Koo and Li, 2016). This assumption is supported by Bruton, Conway and Holgate (2000), who, in their research, note that, as with other reliability coefficients, there is no universally accepted standard for reliability when using the ICC. The ICC values typically range from 0 to 1, with values closer to 1 indicating higher reliability (Bruton et al., 2000). Chinn (1991) recommends that any measure should have an intraclass correlation coefficient of at least 0.6 to be considered useful. The same results were obtained in a study by Jansen, Huijgen, Faber and Elferink-Gemser (2021a), where a systematic review was conducted in PubMed, Web of Science, SPORTDiscus, PsycINFO and Google Scholar to provide an overview of agility tests in the racquet sports tennis, badminton, and squash while evaluating their measurement properties. 20 articles were included, covering 28 agility tests. In these studies, the most frequently used value to assess test-retest reliability is the intraclass correlation coefficient (ICC), where a threshold of 0.50 was indicated as poor, between 0.50 and 0.75 as moderate, between 0.75 and 0.90 as good, and above 0.90 as excellent. However, a stricter acceptable level of reliability using the ICC is provided in the research by Vincent and Weir. In their studies, they categorize ICC into different levels of reliability, ranging from questionable (0.7 to 0.8) to high (> 0.9) (Vincent, 2005; Weir, 2005; Weir and Vincent, 2020). The coefficient of variation (CV) is a commonly used indicator of measurement error, especially in studies with repeated tests (Bruton et al., 2000). This measure corresponds to the standard deviation (SD) of an individual's repeated measurements, expressed as a percentage of the individual's mean test score (Currell and Jeukendrup, 2008). The CV is suitable for comparing reliability between studies with participants of different mean power, such as males versus females. As a dimensionless measure, the CV also facilitates the direct comparison of reliability in performance measures proportional to power (e.g., running speed on a treadmill), regardless of the calibration or scaling of the measures. In essence, a smaller CV indicates better reliability (Currell and Jeukendrup, 2008; Hopkins et al., 2001). A CV of less than 10% has been established as the criterion for acceptable reliability (Atkinson and Nevill, 1998).

When discussing validity, there are three types that can be applied to performance protocols: logical validity, criterion validity, and construct validity. Logical validity or face validity assesses whether a test measures its intended purpose, but it can be challenging to truly assess (Thomas and Nelson, 2001). In contrast, criterion validity provides an objective measure of validity. There are two types of criterion validity: concurrent and predictive (Thomas and Nelson, 2001). Concurrent validity means that the performance protocol is correlated with a criterion measure (Thomas and Nelson, 2001). For example, this could involve correlating laboratory cycling time trial performance with cycling time trial performance in competition. Predictive validity involves using a performance protocol to predict future performance (Thomas and Nelson, 2001). Construct validity refers to the degree to which a protocol measures a hypothetical construct, in this case, performance. It can be measured by comparing two different groups of subjects with different abilities (Thomas and Nelson, 2001). For example, to analyze the construct validity of a cycling performance test, one could compare the performance of professional cyclists with that of recreational cyclists. A test with good construct validity would effectively differentiate between the two groups (Currell and Jeukendrup, 2008).

When discussing the acceptable range of validity, Impellizzeri and Marcora (2009) note that tests should be validated against a criterion, often considered a "gold standard," or an indicator of the construct of interest. A correlation greater than 0.70 between the new test and the reference measure is conventionally used as a benchmark for construct or criterion validity (Impellizzeri and Marcora, 2009). However, according to the same authors, benchmarks should not always be applied too rigidly, and a correlation of 0.65 instead of 0.70 cannot be interpreted as evidence against construct or criterion validity. Furthermore, it's important to consider the confidence interval of these correlations. To determine whether a specific value is acceptable, it is crucial to understand the type of validity under examination. When the correlation reaches 0.90 between a newly constructed test and an already validated test, then we can assert with a high degree of certainty that it represents the same construct. However, if in this case the newly constructed instrument does not offer significant advantages over the old instrument, for example, if it is not shorter or simpler to use, then the new test is merely an unnecessary duplicate. The following section provides a tabular summary of the literature review on the construction/modification of new specific CODS and RAG tests in tennis and other sports. It presents population characteristics and test descriptions with results of reliability and validity measures (Table 1).

Table 1. Review of literature on construction/modification of new specific CODS and RAG tests

Study	*n*	G	Age	Sport	Level	Test	Description	Stimuli	Results
Leone et al. (2006)	38	24 M 14 F	12.6 ± 2.5 13.1 ± 2.5	Tennis	National	Running Speed and CODS Test	Start → Sprint 4m → 90° COD → Sprint 4m → 180° COD → Sprint 8m → 45° COD → Sprint 6m → Finish	-	Reliability: ICC = 0.70 – 0.83 Validity: NR
Barber-Westin et al. (2010)	15	5 M 10 F	13.0 ± 1.5	Tennis	National	Service Box Speed and CODS Test	Start → Sprint → 90° COD → Sprint → 180° COD → Sprint → Finish	-	Reliability: ICC = 0.85 Validity: NR
Eriksson et al. (2015)	34	21 M 13 F	14.0 ± 1.6	Tennis	Regional National	20-Yard CODS Test	Start → Sprint 5yd → 180° COD → Sprint 10yd → 180° COD → Sprint 5yd → Finish	-	Reliability: ICC = 0.91 – 0.95 Criterion-related validity: 0.99
Fernandez-Fernandez et al. (2016)	60	M	12.5 ± 0.3	Tennis	National	Modified 505 CODS Test	Start → Sprint 5m → 180° COD → Sprint 5m → Finish	-	Reliability: ICC = 0.90 – 0.94 Validity: NR
Huggins et al. (2017)	10	NR	15.1 ± 2.6	Tennis	National	Modified CODS T-Test	Start → Sprint 2.5m → 90° COD → Shuttle 2.5m → 90° COD → Shuttle 5m → 90° COD → Shuttle 2.5m → Sprint 2.5m → Finish	-	Reliability: ICC = 0.79 – 0.83 Validity: NR
Huggins et al. (2017)	10	NR	15.1 ± 2.6	Tennis	National	Spider Drill CODS Test	Start → Sprint → 135° COD → Sprint → 180° COD → Sprint → Finish	-	Reliability: ICC = 0.93 – 0.95 Validity: NR

Huggins et al. (2017)	10	NR	15.1 ± 2.6	Tennis	National	Pro-Agility CODS Test	Start → Sprint 5yd → 180° COD → Sprint 10yd → 180° COD → Sprint 5yd → Finish	-	Reliability: ICC = 0.69 – 0.88 Validity: NR
Sekulic et al. (2017)	33	13 M 20 F	18.3 ± 1.1	Tennis	National	20-Yard CODS Test	Start → Sprint 5yd → 180° COD → Sprint 10yd → 180° COD → Sprint 5yd → Finish	-	Reliability: ICC = 0.83 Factorial validity: r ≥ 0.84 (T-Test and Illinois Test)
Sekulic et al. (2017)	33	13 M 20 F	18.3 ± 1.1	Tennis	National	CODS T-Test	Start → Sprint 9.1m → 90° COD → Shuttle 4.6m → 90° COD → Shuttle 9.1m → 90° COD → Shuttle 4.6m → Sprint 9.1m → Finish	-	Reliability: ICC = 0.95 Factorial validity: r ≥ 0.84 (20-Y test and Illinois Test)
Sekulic et al. (2017)	33	13 M 20 F	18.3 ± 1.1	Tennis	National	Illinois test	Start → Sprint 10m → 135° COD → Slalom 3.3m → Sprint 10m → Finish	-	Reliability: ICC = 0.88 Factorial validity: r ≥ 0.84 (20-Y Test And T-Test)
Ulbricht et al. (2016)	902	546 M 366 F	13.1 ± 1.4	Tennis	Regional National	Tennis-Specific Sprint Speed Test	Start → Sprint → 90° COD → Shuttle to FH/BH on stimulus → 180° COD → Hitting ball pendulum → Finish	Light	Reliability: NR Validity: NR

Jansen et al. (2021b)	69	NR	22.0 ± 3.7	Tennis	Regional National	Tennis-Specific Agility Test (TAT)	4 movements at the back of the court around the baseline on stimulus and 1 drop shot	Light	Reliability: ICC = 0.74 Concurrent validity: r = 0.70 (TAT and Spider Drill Test)
Munivrana et al. (2022)	32	21 M 11 F	10.9 ± 1.5	Tennis	National	Tennis-Specific Reactive Agility New Test (TS-RAN)	2 strokes (FH/BH) on the baseline and 2 strokes (FH/BH) on the service line on stimulus	Sound Light	Reliability: ICC = 0.74 Construct/factorial validity: r = 0.70 (TS-RAN and Side Step CODS Test)
Wisnu-Nugroho et al. (2022)	7	NR	NR	Tennis	NR	V Tennis Measuring Instrument	Y-shaped agility test in reaction to a stimulus	Human	Reliability: ICC = 0.50 Content Validity: (Aiken V) = V0.76 – V0.95
Pojskic et al. (2018)	20	M	17.0 ± 0.9	Soccer	National	Soccer-Specific New CODS Test	Y-shaped test with 4 possible CODs (45° and 90°) without response to stimuli	-	Reliability: ICC = 0.84 – 0.89 Validity: NR
Pojskic et al. (2018)	20	M	17.0 ± 0.9	Soccer	National	Soccer-Specific New RAG Test	Y-shaped test with 4 possible CODs (45° and 90°) in response to stimuli	Light	Reliability: ICC = 0.81–0.88 Validity: NR

Sekulic et al. (2019)	32	M	26.2 ± 5.2	Futsal	National	Futsal-Specific New CODS Test	Y-shaped agility test without reaction to the stimuli	-	Reliability: ICC = 0.91 Construct validity: r = 0.08 - 0.31 (Futsal-Specific CODS Test and Futsal-Specific RAG Test)
Sekulic et al. (2019)	32	M	26.2 ± 5.2	Futsal	National	Futsal-Specific New RAG Test	Y-shaped agility test in reaction to the stimuli	Light	Reliability: ICC = 0.77 – 0.80 Construct validity: r = 0.08 - 0.31 (Futsal-Specific RAG Test and Futsal-Specific CODS Test)
Benvenuti et al. (2010)	30	F	23.0 ± 6.0	Futsal Soccer	Regional	Reactive Visual Stimuli Agility Field Test	4 lights placed at the corners of a 7.5 x 7.5 square. Players had to react to 6 stimuli	Light	Reliability: ICC = 0.80 Validity: NR
Farrow et al. (2005)	12	NR	19.5 ± 0.8	Netball	National	Netball-Specific New RAG Test	Y-shaped agility test started with a 4 m sidestep to the left, followed by 2 m to the right. Then, sprint forward for 1m and react to the stimulus	Video	Reliability: ICC = 0.83 Validity: NR
Green et al. (2011)	28	M	19.0 ± 1.3	Rugby	Club	Rugby-Specific New CODS Test	Y-shaped agility test without reaction to a stimulus	-	Reliability: ICC = 0.87 Validity: NR
Green et al. (2011)	28	M	19.0 ± 1.3	Rugby	Club	Rugby-Specific New RAG Test	Y-shaped agility test in reaction to a stimulus	Light	Reliability: ICC = 0.88 Validity: NR

Henry et al. (2013)	42	M	17-19	Australian Football	Club Regional National	Specific New RAG Test	Video reactive agility test	Video Light	Reliability: ICC = 0.81 Validity: NR
Sheppard et al. (2006)	38	M	21.8 ± 3.2	Australian Football	National	Specific New RAG Test	Y-shaped agility test in reaction to the tester movement	Human	Reliability: ICC = 0.88 Validity: NR
Sekulic et al. (2017)	110	M	21.6 ± 3.9	Basketball	National	CODS T-Test	Start → Sprint 9.1m → 90° COD → Shuttle 4.6m → 90° COD → Shuttle 9.1m → 90° COD → Shuttle 4.6m → Sprint 9.1m → Finish	-	Reliability: ICC = 0.91 Validity: NR
Sekulic et al. (2017)	110	M	21.6 ± 3.9	Basketball	National	Specific New RAG Test	Y-shaped agility test in reaction to a stimulus. The player had to go to the lit cone, rebound the ball placed at the top of the cone, and return to the start line as quickly as possible	Light	Reliability: ICC = 0.81 – 0.95 Validity: NR
Scanlan et al. (2014)	12	M	25.9 ± 6.7	Basketball	National	Specific New RAG Test	Y-shaped agility test in reaction to the stimuli	Human Light	Reliability: ICC = 0.89 – 0.99 Validity: NR
Loureiro and Freitas (2016)	43	29 M 14 F	17-19	Badminton	Regional National	Badcamp New Agility test	Sprint to 6 targets placed on a rectangular area (5.6 x 4.2 m) from the start position located in the center, following stimuli	Light	Reliability: ICC = 0.93 Construct validity: r = 0.83 (Badcamp Test and Shuttle-Run CODS Test)

Legend: *n* – number of participants; G – gender; M – male; F – female; CODS - change of direction speed; RAG – reactive agility; ICC - intraclass correlation coefficient; NR – not reported; FH – forehand; BH – backhand

According to the existing literature, a solid number of agility tests with various levels of specificity have been developed and used in tennis over the years, but the majority of the used tests were primarily change of direction (CODS) tests (Barber-Westin, Hermet and Noyes, 2010; Eriksson, Johansson and Back, 2015; Fernandez-Fernandez, Ulbricht and Ferrauti, 2014; Huggins, Jarvis, Brazier, Kyriacou and Bishop, 2017; Leone, Comtois, Tremblay and Léger, 2006; Sekulic et al., 2017; Zemková and Hamar, 2014). For example, in the study of Barber-Westin et al. (2010), a new Service Box Speed and CODS Test was constructed with ICC = 0.85. Similar relative reliability measures (ICC = 0.70 – 0.83) were obtained in the study of Leone et al. (2006) when constructing a new Running Speed and CODS Test. The validity of both mentioned tests is not reported. In addition to new tests, Fernandez-Fernandez et al. (2016) and Huggins et al. (2017) developed new CODS tests by modifying existing ones (505 Test and T-Test), changing the number of changes of direction and angles of movements, and establishing acceptable metric characteristics (ICC > 0.79). Specifically, in the study by Fernandez-Fernandez et al. (2016), the most reliable and valid results of newly designed/modified CODS tests were obtained with ICC values ranging from 0.90 to 0.94. One reason for this could be the largest number of participants used in the testing (60) and the fact that the participants were all male, whereas most other studies included participants of both genders. However, all of these tests did not really consider the cognitive aspect of agility, the "reaction to a stimulus," which would be a much better representation of the kind of agility performance needed in a real tennis match rally situation.

Despite the importance of reactive agility in tennis, which involves factors such as perception and decision-making, the main problem is that there is a very limited number of scientific studies that have addressed this motor dimension, especially in specific conditions. More specifically, a comprehensive systematic literature search yielded that there are only a few tennis-specific reactive agility tests, including a response to a stimulus, showing reliable and valid results (Ulbricht, Fernandez-Fernandez, Mendez-Villanueva and Ferrauti, 2016; Jansen, Elferink-Gemser, Hoekstra, Faber and Huijgen, 2021b; Munivrana, Jelaska and Tomljanović, 2022; Wisnu-Nugroho, Abdul and Fauzi, 2022).

The test used in the study of Ulbricht et al. (2016) included both physical and cognitive aspects of agility in the test, but some of the parameters used in the test made it more of a tennis-specific sprint speed test than a real reactive agility test, and the test has no reliable and valid outcomes. Furthermore, one of the rare tennis-specific reactive agility tests (TAT) for monitoring tennis players has been designed in the research by Jansen et al. (2021b). In this study, for relative reliability, the intraclass correlation coefficient (ICC) was calculated using a two-way mixed ANOVA type absolute agreement single measure. An ICC of < 0.50 was indicated as poor, between 0.50 and 0.75 as moderate, between 0.75 and 0.90 as good, and > 0.90 as excellent. According to these established criteria, the TAT showed moderate relative reliability with an ICC of 0.74 (95% CI 0.34 - 0.92; p < 0.01). The concurrent validity of the Spider Drill and the TAT was assessed using Pearson correlation (1-tailed), where a correlation around 0.60 - 0.70 was considered to be sufficient. A significant positive moderate correlation of 0.70 (p < 0.01) was found between the TAT and the Spider Drill test. Moreover, the association between tennis performance and the TAT showed significant positive moderate correlations for both boys (r = 0.67; p < 0.01) and girls (r = 0.72; p < 0.01). In conclusion, the test has shown solid test-retest reliability and concurrent validity in relation to a popular generic Spider Drill agility test (Huggins et al., 2017). However, although the TAT test has been designed to be used in a practical setting by sports scientists and coaches, the test still requires some technical equipment and setting to be arranged (cones and light positions, etc.) for it to be successfully conducted. In addition to the mentioned research, Munivrana et al. (2022) designed a tennis-specific reactive agility test (TS-RAN) with a movement pattern that simulates the actual situation in the game, with participants not knowing the direction of movement in advance. They performed two strokes (forehand or backhand) on the baseline and two strokes (forehand or backhand) on the service line. The newly constructed tennis-specific reactive agility test (TS-RAN) showed to be on the margin between moderate and good reliability, with an ICC of 0.74 (95% CI 0.48–0.92; p < 0.01). The construct/factorial validity of the steps to the side lateral agility test (STSLA) and the newly constructed tennis-specific reactive agility test (TS-RAN) was assessed using factor analysis (Guttman–Kaiser criterion of extraction). A positive moderate correlation of 0.79 (p < 0.01) was found between the TS-RAN and STSLA test. Additionally, another study was conducted with the aim of assessing the reliability of reactive agility measurements in tennis performance. In this study, a ´V Tennis measuring instrument´ with a "Y" shape construction was developed (Wisnu-Nugroho et al., 2022). The reliability criteria were established such that an ICC value of 0.40 or lower could be interpreted as a low level of agreement, an ICC value of 0.41-0.75 as a good level of agreement, and an

ICC value of 0.76-1.00 as a high level of agreement. Comparing the aforementioned tests, it can be determined that the TAT and TS-RAN are currently the two best newly constructed tests for assessing RAG ability. Both tests have shown similar results in terms of reliability and validity, but it is important to note that there are also differences between them. These differences are evident in the number of participants, age, level, and the method of implementation. Accordingly, the construction of a new test through this doctoral dissertation has certainly contributed to the development of this scientific field.

Regarding other sports, there is a noticeable trend in the development of sport-specific tests aimed at evaluating various types of reactions, movements, and response times in agility-based sports. What can be observed is that, similar to tennis, most research covers tests change of direction speed, with limited exploration of specific reactive agility. Research has been conducted on samples of Australian football players (Henry, Dawson, Lay and Young, 2013; Henry, Dawson, Lay and Young, 2016; Sheppard, Young, Doyle, Sheppard and Newton, 2006), rugby players (Green, Blake and Caulfield, 2011), netball players (Farrow, Young and Bruce, 2005), basketball players (Sekulić et al., 2017; Lockie, Jeffriess, McGann, Callaghan, and Schultz, 2014; Scanlan, Humphries, Tucker and Dalbo, 2014), volleyball players (Sattler, Sekulic, Hadzic, Uljevic and Dervisevic 2012; Villarejo-Garcia, Moreno-Villanueva, Soler-López, Reche-Soto and Pino-Ortega, 2023), soccer players (Zouhal et al., 2018; Spierer, Petersen, Duffy, Corcoran and Rawls-Martin, 2010; Knoop, Fernandez-Fernandez and Ferrauti, 2013; Pojskic et al., 2018; Krolo et al., 2020), hockey players (Morland, Bottoms, Sinclair and Bourne, 2013), futsal players (Benvenuti, Minganti, Condello, Capranica and Tessitore, 2010; Sekulić et al., 2019; Sekulić et al., 2021; Zeljko, Gilic and Sekulic, 2020) and badminton players (Loureiro and Freitas, 2016). Most of the mentioned tests were constructed in a way that the format was a Y-shape test with a reaction to stimulus (lights), and the ICC was > 0.70. Such results can be considered acceptable, but with the aim of improving the test characteristics to achieve an even higher interclass correlation coefficient. The advantage of using such sport-specific tests over general tests lies in the fact that their execution requires knowledge of the specific technique of each sport or sport-specific movement structures (Paul, Gabbett and Nassis, 2016). Based on this, it is assumed that sport-specific tests provide a better insight into the true state of athletic performance and enable differentiation between athletes based on the small differences that exist at the elite level of competition (Sattler et al., 2015).

In conclusion of this section of the doctoral dissertation, it can be noted that there has been a rapid increase in the number of studies published with relevance to agility, particularly testing and training. It's important to emphasize that there is no consensus on standard values for acceptable reliability using ICC and validity using the correlation coefficient. Sport-specific tests provide more detailed information about the actual state of those traits and abilities that ultimately ensure a player's success at the elite competitive level (Sekulić et al., 2017). Additionally, such field-based tests better describe the player's motor performance efficiency related to technical execution compared to basic tests (Reilly et al., 2009). In terms of newly constructed CODS tests in tennis, the fundamental problem is that they are based on modifying existing CODS tests by only changing the number of changes of direction and angles of movements. Additionally, for most of these tests, only relative reliability has been defined through ICC, while validity has not been measured. In line with that, it is clear that additional measures of reliability should be incorporated to provide a comprehensive assessment of the test's consistency. Also, some tests have better reliability and validity, which can be attributed to factors such as the number of participants, age, level of play, and the implementation of the test. For example, some tests that have better reliability usually have a larger number of participants, a clearly defined gender, and a higher level of play. This can be attributed to the fact that more experienced players are likely to perform better on the test, making it more reliable. Therefore, it is very important to create a CODS test that will also provide a acceptable level of reliability and validity for younger participants. An even greater problem arises with the construction of new RAG tests in tennis, where only a few such tests have been found so far, but with significant shortcomings. One such test is more of a tennis-specific sprint speed test than a real reactive agility test, with undefined reliability and validity. Additionally, some tests (TAT and TS-RAN) show better and more concrete results but still require technical equipment and specific settings to be arranged (complicated and not clearly defined cone and light positions, imitation of hitting a ball which is likely to be less intentional than hitting a real tennis ball, excessive influence of human factors). Furthermore, when it comes to TAT and TS-RAN tests, it can be seen that the obtained results of reliability and validity are similar, but there are also differences among participants in terms of age, gender, and level of play. In line with that, additional research with the new test is certainly needed, both for younger and older participants. Finally, it is worth mentioning that in one of the tests (V Tennis measuring instrument), the gender, age, and level of participants are not even reported. Considering all the aforementioned, there is a clear need for the construction of new RAG tests in tennis that would minimize the mentioned shortcomings. In line with all of the above, one of the aims of this dissertation is to validate a new test for assessing change of direction speed and reactive agility in young tennis players. This way, training and diagnostic methods can be systematically developed to enable players to achieve higher levels of tennis more efficiently.

Speed-explosive properties encompass speed, agility and explosive power, representing a set of motor abilities important for performance in tennis (Cooke, Quinn, and Sibte, 2011; Munivrana, Filipčić and Filipčić, 2015; Filipčić and Filipčić, 2005). These abilities are commonly treated together due to several shared characteristics: they utilize the same energy resources, stimulate the nervous system in a similar manner, have common factors influencing the level of each ability and require the same prerequisites for intense training of each motor ability (Pearson, 2001). It is also believed that athletes with pronounced speed-explosive properties have better control over their bodies in urgent training and competitive situations, greatly contributing to the game and injury prevention (Pearson, 2001). The following section provides a tabular summary of the literature review on the correlation between anthropometric, speed, agility and explosive power in tennis. It presents population characteristics and test descriptions with the results of Pearson's correlation coefficient (r) (Table 2).

Table 2. Review of literature on the correlation between anthropometric, speed, agility and explosive power in tennis

Study	*n*	G	Age	Exp/Level	Sport	Tests	Correlations
Filipčić and Filipčić (2005)	52	M	13 years	Experience: NR Level: National	Tennis	Body height (BH) Body weight (BW) 20m sprint (S20m) Quarter jump (QJ) Fan drill CODS test (FD)	r = -0.20 (BH and FD) r = -0.29 (BW and FD) r = 0.40 (S20m and FD) r = -0.46 (QJ and FD)
Leone et al. (2006)	38	24 M 14 F	12.6 ± 2.5 13.1 ± 2.5	Experience: >2 years of training Level: Elite	Tennis	5m sprint (S5m) 20m sprint (S20m) Tennis drill CODS test (TD)	r = 0.03 – 0.39 (S5m and TD) r = 0.64 (S20m and TD)
Pauole et al. (2015)	152	M	College-aged	Experience: NR Level: Recreational Competitive	Tennis	40y sprint (S40Y) T-test (TT) Hexagon test (HT) Vertical jump (VJ)	r = 0.55 (S40Y and TT) r = 0.24 (S40Y and HT) r = -0.49 (VJ and TT) r = -0.27 (VJ and HT) r = 0.42 (and TT and HT)
Munivrana et al. (2015)	154	M	15-18 years	Experience: NR Level: National	Tennis	5m sprint (S5m) 20m sprint (S20m) Quarter jump (QJ) Vertical jump (VJ) 9×6m CODS test (9x6m) Fan drill CODS test (FD)	r = 0.58 (S5m and 9x6m) r = 0.27 (S5m and FD) r = 0.14 (S20m and 9x6m) r = 0.25 (S20m and FD) r = 0.29 (QJ and 9x6m) r = 0.40 (QJ and FD) r = 0.03 (VJ and 9x6m) r = 0.12 (VJ and FD)

Kumar (2017)	40	M	15.1 ± 0.4	Experience: 6-8 years of training Level: National	Tennis	Body height (BH) Body weight (BW) 10m sprint (S10m) 20m sprint (S20m) 20m shuttle run test (SHT20m) Box drill CODS test (BD) Spider drill CODS test (SD)	r = -0.21 (BH and SD) r = -0.15 (BW and SD) r = 0.82 (S10m and SD) r = -0.76 (S20m and SD) r = -0.76 (SHT20m and SD) r = 0.76 (BD and SD)
Sekulic et al. (2017)	33	13 M 20 F	18.3 ± 1.1	Experience: >2 years of training Level: National	Tennis	T-test (TT) T-test with a racquet (TTR) 20y CODS test with a racquet (20YR) Illinois CODS test with a racquet (IR)	r = 0.91 (TT and 20YR) r = 0.97 (TT and TTR) r = 0.94 (TT and IR)
Hernandez-Davo et al. (2021)	35	21 M 14 F	14.3 ± 1.6	Experience: 6.2 ± 2.5 years of training Level: National	Tennis	5m sprint (S5m) 10m sprint (S10m) 20m sprint (S20m) Hexagon test (HT) T-test (TT) Countermovement jump (CMJ) Triple leg-jump test (TLJ)	r = 0.40 (S5m and HT) r = 0.57 (S10m and HT) r = 0.60 (S20m and HT) r = 0.60 (CMJ and HT) r = 0.68 (TLJ and HT) r = 0.41 (S5m and TT) r = 0.54 (S10m and TT) r = 0.63 (S20m and TT) r = 0.56 (CMJ and TT) r = 0.72 (TLJ and TT) r = 0.76 (HT and TT)

Jansen et al. (2021b)	69	NR	22.0 ± 3.7	Experience: NR Level: Regional National	Tennis	Spider drill CODS test (SD) Tennis-Specific Agility Test (TAT)	r = 0.70 (SD and TAT)
Munivrana et al. (2022)	32	21 M 11 F	10.9 ± 1.5	Experience: >2 years of training Level: National	Tennis	Side step CODS test (SS) Tennis-Specific Reactive Agility New Test (TS-RAN)	r = 0.79 (SS and TS-RAN)

Legend: *n* – number of participants; G – gender; M – male; F – female; Exp - tennis experience; CODS - change of direction speed; NR – not reported

Reviewing the existing literature, it can be observed that there are studies focused on establishing the correlation between speed, agility, and explosive power in tennis. However, when it comes to agility, it is important to note that most of these studies are based on CODS tests. For example, Filipčić and Filipčić (2005) in their research on a sample of 52 young male tennis players (13 years old) found a low correlation between anthropometric characteristics (Body height and weight) and the Fan drill CODS test, and a moderate correlation between the 20m sprint, Quarter jump, and the mentioned Fan drill CODS test. Furthermore, Leone et al. (2006) established a low correlation between short speed tests (5m sprint) and the Tennis drill CODS test, but a high correlation was obtained with longer speed tests (20m sprint). Such an assumption was confirmed in the research by Pauole, Madole, Garhammer, Lacourse, and Rozenek (2000), where a moderate correlation was shown between the 40-yd sprint and the results in the CODS T-test and slightly lower with the Hexagon CODS test. Comparable results were obtained between the Vertical jump and the mentioned CODS tests. Additionally, in the same study, a moderate correlation was determined between the T-test and the Hexagon test. However, in a study by Munivrana et al. (2015), it was discovered that a high correlation also exists between the 5m sprint test and the Fan drill CODS test, but not with the 9×6m CODS test in 154 male junior tennis players aged between 15 and 18 years, ranked by the Slovenian Tennis Association. In the same study, a moderate correlation was found between the Quarter jump test and the mentioned CODS tests, but when it comes to the Vertical jump test, a very low correlation was defined. Kumar (2017), in his research on a sample of 40 young male tennis players (15.1 ± 0.4 years), found a low correlation between anthropometric characteristics (body height and weight) and the Spider drill CODS test. However, all other measured tests (10m sprint, 20m sprint, 20m shuttle run, and Box drill CODS test) showed a large correlation with the mentioned Spider drill CODS test. Similar findings were also established by Hernandez-Davo et al. (2021), where they found moderate to large correlations between all sprint, horizontal jump, and vertical jump tests with the CODS T-test and Hexagon test in a study conducted on 35 junior male and female tennis players. Additionally, in the study by Sekulic et al. (2017), on a sample of 33 junior tennis players (18.3 ± 1.1 years), a large correlation was determined between different CODS tests (T-test, 20y test, Illinois test) with and without a racket. When it comes to the correlation between speed, agility, and explosive power with RAG tests in tennis, there is a clear lack of research on this topic. A review of the literature revealed a very low number of such studies. Jansen et al. (2021b), in their research on a sample of 69 junior players with unreported gender, identified a positive moderate correlation between the Spider drill CODS test and the Tennis-Specific Agility Test. Similarly, Munivrana et al. (2022) found a positive moderate correlation between the Side-Step CODS test (STSLA) and the newly constructed Tennis-specific Reactive Agility Test (TS-RAN) among 32 youth tennis players (21 males and 11 females; 10.8 ± 1.5 years). What can be noticed from all the mentioned studies is the sample of participants, which includes young tennis players during both the early puberty and puberty phases. It is important to highlight this because this period is essential for early talent identification, skill development, injury prevention, and tailored training programs aimed at maximizing athletic potential and performance. Additionally, tests for agility and other athletic attributes in pubertal children serve multiple purposes, including long-term athlete development, psychological well-being, health promotion, social integration, and sport enjoyment. These efforts contribute to the holistic development of children, both as athletes and individuals, setting the stage for a lifetime of physical activity and sports participation. Overall, the simplicity and efficiency of tests for agility and other athletic attributes in pubertal children contribute to a positive testing experience, accurate assessment of abilities, and effective monitoring of progress over time. After reporting the results of all studies, it is essential to observe the connection, i.e., generalized knowledge which is a derivation of all the results obtained from all the studies reviewed. The variation in correlations observed between different studies can be attributed to several factors that modify these relationships. Firstly, the gender, age and developmental stage of the participants play a crucial role, as the physical and physiological characteristics of young athletes can vary significantly during puberty, affecting their performance in different tests. For instance, differences in maturation can influence muscle strength, coordination, and overall agility, leading to varying degrees of correlation between speed, agility, and explosive power tests. Research involving older participants, who have more experience and a higher level of play, has shown slightly greater correlations compared to studies with younger participants. This highlights the importance of finding and utilizing tests that highly correlate with younger participants as well, which is precisely what this doctoral dissertation aims to demonstrate. Additionally, the specific nature of the tests used in each study can impact the correlations. Different CODS tests, for example, may measure slightly different aspects of agility and movement efficiency, thus leading to different correlation outcomes. The testing environment and conditions, such as the type of surface and even the presence of a racket, can also influence test results and correlations.

From the mentioned studies regarding the correlation between performance in basic motor tests and performance in newly constructed CODS and RAG tests in tennis, it can be concluded that there are limitations in scientific research on this topic. It can be observed that correlations between speed, agility, and explosive power vary across different types of CODS tests due to differences in gender, age, and level of play, and none of the mentioned correlations were made with newly constructed CODS tests but rather with well-known and basic tests. Based on the studies reviewed, it is evident that the participants studied predominantly consisted of male tennis players, with varied levels of tennis experience. Future research should prioritize studying female tennis players across different age groups, including juniors, adults, and seniors. Since the sample of participants in this doctoral dissertation consisted solely of male subjects, this can be considered as one of its shortcomings, and it would certainly be beneficial to conduct a similar study, for instance, with senior female tennis players. However, an even greater problem and a greater need for new studies on this topic arise when considering the correlation between speed, agility, and explosive power with RAG tests in tennis. None of the mentioned studies presented the correlation between anthropometric characteristics and motor abilities of speed and power with RAG tests. Instead, only comparisons between existing CODS and newly constructed RAG tests were made. Furthermore, one of the studies did not report either the gender or experience of tennis players, and the level varied from amateur to professional players. Considering all of the above, it is evident that there is a need to demonstrate the correlation between anthropometric variables and motor abilities with reactive agility performance.

When it comes to other sports, a review of the literature reveals a significant trend in establishing the correlation between speed, agility, and explosive power. In a study that investigated 12 first-division male seniors, Alemdaroglu (2012) reported significant correlations between the countermovement jump, the squat jump, and the 30m sprint with a standard test of CODS (T-Test). However, there was no statistically significant correlation between the CODS (T-Test) and percent of body fat as an anthropometric measure. Additionally, Sisic, Jelicic, Pehar, Spasic and Sekulic (2016) reported a high correlation between horizontal jumping capacity and CODS in 92 elite male juniors while in a study by Spiteri et al. (2014), significant correlations between maximal dynamic, isometric, concentric and eccentric strength with CODS were found in 12 elite female basketball players. Both studies reported that anthropometric characteristics were not strongly related to agility performance, but leg length is found to be negatively associated with performance in basketball-specific agility. Furthermore, in an investigation of youth elite basketball players of both genders, unilateral jump performance and body mass were the most important correlates with CODS for boys and sprint performance was strongly correlated with CODS in girls (74.8% of the variance) (Delextrat, Grosgeorge and Bieuzen, 2015). Also, few studies have described the correlations between certain psycho-motor capacities and reactive agility in male basketball players (Delextrat et al., 2015; Scanlan et al., 2014; Scanlan, Tucker and Dalbo, 2015; Pehar et al., 2018; Lockie et al., 2014; Jeffriess, Schultz, McGann, Callaghan and Lockie, 2015; Sekulic et al., 2017). In one study, the authors reported a moderate correlation between 10m sprint times and reactive agility in a sample of 20 senior basketball players (Lockie et al., 2014). A study involving 12 senior basketball players found a strong correlation between response time and decision-making time in relation to reactive agility. The study highlighted that cognitive factors had the most significant impact on the players' reactive agility performance (Scanlan et al., 2014). In a study by Pehar et al. (2018), it was established that horizontal jump performance (Broad jump test) was found to be an important predictor of basketball-specific CODS. Additionally, anthropometric variables and body build are specifically associated with reactive agility in 88 high-level male basketball players. Also, in a study by Trecroci et al. (2016), it was indicated that reactive agility is affected not only by speed-explosive abilities but also by various cognitive factors such as perception, anticipation, and decision-making speed during the game. Furthermore, Little and Williams (2005) reported that there is no correlation between acceleration speed and maximal speed with agility in the group of 106 professional Australian soccer players. Similar results were obtained by Young, Hawken and McDonald (1996), where no significant correlations were shown between straight sprinting tests and agility tests in either Australian soccer or Australian professional football players. Also, when examining Australian footballers, researchers found a weak correlation between jumping abilities and reactive agility performance (Henry et al., 2013). Also, Mayhew, Piper, Schwegler and Ball (1989) reported low common variances of 21% between tests for straight sprinting speed and agility.

Spaniol, Flores, Bonnette, Melrose and Ocker (2010) investigated the correlation between speed and change of direction speed of professional football players and found a significant correlation between the 40-yard dash test and the 20-yard shuttle test. Furthermore, Ramos et al. (2009) investigated the performance of junior elite soccer players through physical tests according to positional roles and did not find significant differences between positional roles and the agility test. Sporiš, Milanović, Trajković and Joksimović (2011) in their research showed that an agility test with the ball has not shown a significant correlation with speed and quickness. This assertion was confirmed by Koklu, Alemdaroglu, Ozkan, Koz and Ersoz (2015) in their study, where they demonstrated that no correlation was found between the vertical jump test and the agility test with the ball, but there was a strong correlation without the ball in 15 young soccer players (16.0 ± 0.8 years). A similar result was also reported in the study conducted by Erikoglu and Arslan (2016) on 14-year-old soccer players (n = 25), which showed a moderate correlation between vertical jump and agility without the ball. Marković, Sekulić and Marković (2007) found that four independent factors, such as explosive strength, elastic strength, agility, and maximal strength, have a poor relation to agility performance. In line with that, Vescovi and McGuigan (2008) in their research mention a weak negative correlation between vertical jump and agility. In contrast, Conlon, Haff, Nimphius, Tran and Newton, (2013) found a significant relation between the vertical jump test and agility test performances in 134 professional athletes of different sports. Findings of their study have shown that vertical jump velocity is the strongest determinant of speed and agility performance. A significant correlation between agility and explosive power of the lower limb in elite adolescent handball players was concluded by Hermassi, Fadhloun, Chelly and Bensbaa (2011) and Pereira et al (2018). There are also some studies focused on establishing the correlation between speed, agility, and explosive power in samples of rugby players (Condello et al., 2013; Gabbett, Kelly and Sheppard, 2008; Gabbett, Jenkins and Abernethy, 2011; Meir, Newton, Curtis, Fardell and Butler, 2001; Wheeler and Sayers, 2010) as well as in samples of hockey players (Ferreira et al., 2019) and softball players (Nimphius, McGuigan and Newton, 2010).

In accordance with all that has been mentioned, it can be concluded that this dissertation will attempt to answer the question of whether there is a correlation between performance in basic motor tests and performance in newly constructed change of direction speed and reactive agility tests in young tennis players. The assumption is that there is a significant correlation between anthropometric variables and motor abilities with change of direction speed and reactive agility performance.

Various training interventions have the potential to enhance the performance of tennis players. For example, resistance training can lead to an increase in serve velocity (Kraemer et al., 2003), while strength training can improve the speed of forehand and backhand hits (Terraza-Rebollo, Baiget, Corbi and Planas Anzano, 2017). Additionally, core training, balance training and sprint training have been shown to positively impact the speed and strength of tennis players (Sannicandro, Cofano, Rosa, and Piccinno, 2014; Bashir, Nuhmani, Dhall, Muaidi, 2019; Moya-Ramon et al., 2020). High-intensity interval training has the capacity to enhance the aerobic performance of young tennis athletes (Fernandez-Fernandez, Sanz, Sarabia, Moya, 2017). Notably, among the various types of exercises, plyometric training has become a highly popular form of physical conditioning for athletes at all competitive levels (Markovic and Mikulic, 2010). It involves a stretch-shortening cycle (SSC) consisting of a lengthening action (eccentric movement) followed by a shortening action (concentric movement) (Chmielewski, Myer, Kauffman and Tillman, 2006). The underlying mechanism of plyometric training primarily comprises two components. The first part converts the elastic energy stored during muscle stretching into the power output of concentric contraction (Wilk et al., 1993). The second part involves the utilization of proprioceptor signals generated during muscle stretching to detect muscle tension and length (stretch reflex) (Bal, Singh, Dhesi and Singh, 2012). These sensory signals then transmit nerve impulses to the spinal cord, conveying information to alpha motor neurons that activate agonist muscles, recruit motor units, and inhibit the contraction of antagonist muscles (Potach, 2004). Meanwhile, the SSC functions as a model explaining the energy-storing capabilities of the series elastic component and the activation of the stretch reflex, allowing for a maximal increase in muscle recruitment in the shortest possible time (Potach, 2004).

Based on the physiological principles mentioned above, the focus and application of plyometric training have evolved over the last few years. Specifically, plyometric training has been increasingly utilized to enhance general human neuromuscular function (Markovic, Jukic, Milanovic and Metikos, 2007; Fatouros et al., 2020; Hakkukinen, Komi, and Alen, 1985), improve performance in both explosive activities (Brown, Mayhew and Boleach, 1986; Matavulj, Kukolj, Ugarkovic, Tihanyi and Jaric, 2001; Salonikidis and Zafeiridis, 2008), and endurance athletic events (Spurrs, Murphy and Watsford, 2003; Saunders et al. 2006). Additionally, several studies have demonstrated that plyometric training can enhance biomechanical technique and neuromuscular control during high-impact activities, reducing the risk of lower-extremity injuries in team sports (Hewett, Stroupe, Nance and Noyes, 1996; Mandelbaum et al., 2005; Myklebust et al., 2003; Petersen et al., 2005; Huang, Jankaew and Lin, 2021). Lastly, experimental evidence suggests that plyometric training may induce not only beneficial neuromuscular adaptations but also positively impact bone health (Kato et al., 2006; Witzke et al., 2000) and musculo-tendinous adaptations (Kubo et al. 2007; Grosset, Piscione, Lambertz and Pérot, 2009).

Based on all the information presented, it can be concluded that plyometric training holds the potential and provides a training advantage for improving sports performance in various athletic populations (Markovic and Mikulic, 2010). Furthermore, plyometric training has proven effective in enhancing various aspects of athletes' physical performance, including sprinting, jumping, muscle strength, balance, endurance, agility, and flexibility. These positive effects have been observed across different age groups, genders, training backgrounds, and competition levels (Agostini, de Godoy Palomares, de Almeida Andrade, Uchoa and Alves, 2017; Bogdanis et al., 2019; Fathi et al., 2019; Li et al., 2019; Bouteraa, Negra, Shephard and Chelly, 2020; Jlid et al., 2020; Tammam and Hashem, 2020; Ahmadi et al., 2021; Rojano Ortega, Berral-Aguilar and Berral de la Rosa, 2022; Romero et al., 2021; Sáez De Villarreal et al., 2021; Kim, Rhi, Kim and Chung, 2022; Kosova, Beyhan and Kosova, 2022).

Table 3. Review of literature on the effect of various plyometric training programs on speed, agility and explosive power in tennis

Study	*n*	G	Age	Exp/Level	Programs	Groups	Tests	Effects
Salonikidis and Zafeiridis (2008)	64	M	21.1 ± 1.3	Experience: 2–3 years of training Level: Novice	Frequency: 3 times/week Time: NR Length: 9 weeks	Plyometric training (EG1) Plyometric and tennis regular drills (EG2) Control group (CG)	Reaction time (RT) Side sprint (4 m, 12 m) (SS) Forward sprint (4 m, 12 m) (FS) Drop jump (DJ) Maximum isometric force (leg) (Fmax)	EG1:RT↑* (27%), 4mSS↑* (9%), 4mFS↑* (8%), 12mFS↔, DJ↑* (15%), Fmax↑* (8%) EG2: RT↑* (29%), 4mSS↑* (6%), 4mFS↑* (6%), 12mFS↑* (3%), DJ↑* (12%), Fmax↑* (8%)
Gelen et al. (2012)	26	NR	15.1 ± 4.2	Experience: >8.4 ± 3.8 years of training Level: Elite	Frequency: NR Time: ~30 min Length: NR	Dynamic exercises (EG1) Plyometric exercises (EG2) Control group (CG)	Serve velocity (SV)	EG1, EG2: SV↑ (1-3%)
Behringer et al. (2013)	36	M	15.0 ± 1.6	Experience: ~6 years of training Level: National	Frequency: 2 times/week Time: 45 min Length: 8 weeks	Resistance training (EG1) Plyometric training (EG2) Control group (CG)	Serve velocity (SV) Serve accuracy (SA) 10RM test (pull down machine, leg press	EG1: SV↔, SA↑ (6%), 10RM↑* (24%) EG2: SV↑ (3%), SA↑ (4%), 10RM↑* (16-20%)

Olçucu et al. (2013)	40	M	20-25 years	Experience: NR Level: National	Frequency: 2 times/week Time: 35 min Length: 8 weeks	Plyometric training (EG) Control group (CG)	Serve velocity (SV) Isokinetic tests (upper and lower extremities)	EG: SV↑* (15%), Isokinetic tests↑* (>5%)
Barber-Westin et al. (2015)	42	Mix	14.0 ± 2.0	Experience: >2 years of training Level: National	Frequency: 3 times/week Time: NR Length: 8 weeks	Neuromuscular and performance training (EG)	Single-leg jump (SLJ) CODS (Baseline and service box speed) (BSB) 1-court suicide run (1SR)	EG: SLJ↑* (10%), BSB↑* (8%), 1SR↑* (14%)
Fernandez-Fernandez et al. (2015)	16	M	16.9 ± 0.5	Experience: 8.0 ± 2.6 years of training Level: Elite	Frequency: 2 times/week Time: 30-60 min Length: 8 weeks	Explosive strength and repeated sprint training (EG) Control group (CG)	Sprint (10, 20 and 30 m) Repeated sprint test (RST) Countermovement jump (CMJ) Aerobic endurance (VIFT)	EG: S10m↑*, RST↑*, CMJ↑* (2-3%) S20 m↔, S30 m↔, VIFT↔
Fernandez-Fernandez et al. (2016)	60	M	12.5 ± 0.3	Experience: >2 years of training Level: International	Frequency: 2 times/week Time: 30-60 min Length: 8 weeks	Plyometric training (EG) Control group (CG)	Sprint (5, 10 and 20 m) CODS (5-0-5 Test) Countermovement jump (CMJ) Medicine ball throw (MBT) Standing long jump (SLJ)	EG: S5m↑*, S10m↑*, S20m↑*, 5-0–5↑*, CMJ↑*, MBT↑*, SLJ↑* (3-10%)

Rathore (2016)	60	M	18–23 years	Experience: NR Level: Professional	Frequency: 3 times/week Time: 45 min Length: 8 weeks	Plyometric training (EG1) Resistance training (EG2) Control group (CG)	CODS (Illinois test)	EG1: Illinois test↑* (11%) EG2: Illinois test↔
Fernandez-Fernandez et al. (2018)	16	M	12.9 ± 0.4	Experience: 3.0 ± 1.2 years of training Level: Elite	Frequency: 2 times/week Time: 20-40 min Length: 8 weeks	Neuromuscular training before tennis-specific training (EG1) Neuromuscular training after tennis-specific training (EG2)	Serve velocity (SV) Sprint (5, 10 and 20 m) Countermovement jump (CMJ) Medicine ball throw (MBT) CODS (5-0-5 Test)	EG1: SV↔, S5m↑, S10m↑, S20m↑, CMJ↑, MBT↑, 5-0-5↑ (2-8%) EG2: SV↔, S5m↓, S10m↑, S20m↔, MBT↔, CMJ↔, 5–0-5↓ (1-5%)
Lakshmikanth et al. (2018)	30	Mix	18–22 years	Experience: NR Level: College	Frequency: 1 time/week Time: NR Length: 6 weeks	Plyometric training (EG) Control group (CG)	CODS (Illinois test) CODS (Tennis-specific test)	EG: Illinois test↑* (13%), Tennis-specific test↑* (7%)

Ziagkas et al. (2019)	24	M	20.9 ± 0.7	Experience: 1–3 years of training Level: Amateur	Frequency: 2 times/week Time: 30-60 min Length: 8 weeks	Plyometric training (EG) Control group (CG)	CODS (Hexagon test) CODS (Spider drill test)	EG: Hexagon test↑* (22%), Spider test↑* (29%)
Mohanta et al. (2019)	40	M	18–25 years	Experience: >2 years of training Level: National	Frequency: 2 times/week Time: 30-60 min Length: 8 weeks	Plyometric training (EG1) Circuit training (EG2)	Sprint (50 m) 1RM test (chest press) Vertical jump (VJ) CODS (T-test)	EG1 and EG2: S50m↑* (>12%), 1RM↑* (>10%) VJ↑* (>22%) T-test↑* (>13%)
Fernandez-Fernandez et al. (2020)	28	M	15.1 ± 1.2	Experience: >2 years of training Level: National	Frequency: 3 times/week Time: 20-32 min Length: 8 weeks	Neuromuscular training (EG1) Dynamic warm up training (EG2)	Serve velocity (SV) Sprint (5, 10 and 20 m) CODS (5-0-5 Test) Countermovement jump (CMJ) Medicine ball throw (MBT) Shoulder strength (SS) Shoulder range of motion (ROM)	EG1 and EG2: SV↔, S5m↑* S10 m↑*, S20 m↑* (2-4%), 5-0-5↔, CMJ↑* (3-11%), MBT↑* (4-10%), SS↑*, ROM↑*
Hotwani et al. (2021)	31	Mix	15–18 years	Experience: NR Level: National	Frequency: NR Time: 60 min Length: 3 weeks	Plyometrics and sprint training (EG)	CODS (T-test) CODS (Illinois test)	EG: T-test↑* (22%), Illinois Test↑* (18%)

Kanabar et al. (2022)	40	Mix	11–18 years	Experience: >2 years of training Level: National	Frequency: 3 times/week Time: 30 min Length: 6 weeks	Plyometric training (EG1) Agility ladder training (EG2)	Sprint (20 m) CODS (Illinois test) Standing long jump (SLJ)	EG1 and EG2: S20m↑*, Illinois Test↑*, SLJ↑* (5-15%)
Novak et al. (2023)	30	Mix	12-14 years	Experience: >2 years of training Level: National	Frequency: 2 times/week Time: 30-45 min Length: 6 weeks	Plyometric training (EG) Control group (CG)	Sprint (5, 10 and 20 m) Squat jump (SJ) Countermovement jump (CMJ) Single-leg countermovement jump (SLCMJ) Single-leg triple jump (SLTJ) Standing long jump (LJ) CODS (T-test) CODS (20-Yard test) RAG (WS-S)	EG: S5m↑ (6%), S10m↑ (9%), S20m↑ (6%), CMJ↑* (10%), SLCMJ↑* (12%), SLTJ↑* (7%), LJ↑ (3%), CODS↑ (4%), RAG↑ (8%)
Gamlath and Thotawaththa (2023)	16	M	16–17 years	Experience: NR Level: NR	Frequency: 3 times/week Time: NR Length: 6 weeks	Plyometric training (EG) Control group (CG)	Sprint (10m) Vertical jump (VJ) CODS (T-test) CODS (5-0-5 test)	EG: S10m↑* (19%), VJ↑* (16%), T-test↑* (8%), 5-0-5↑* (15-21%)

Legend: *n* – number of participants; G – gender; M – male; F – female; Exp - tennis experience; CODS - change of direction speed; RAG – reactive agility; NR – not reported; ↑ - significant within-group improvement; ↔ - non-significant within-group; * - statistical significance

In recent years, several reviews and meta-analyses focusing on the effect of plyometric training on athletic performance characteristics have been published (Silva et al., 2019; Ramirez-Campillo et al., 2020a; 2020b; 2021a; 2021b). However, these meta-analyses encompassed athletes from a variety of sports, including volleyball, soccer, and basketball. Since the effects of plyometric training may vary depending on the athlete's sports background, the findings of these studies cannot be directly applied to tennis players (Ramirez-Campillo et al., 2021b; Sole, Ramírez-Campillo, Andrade and Sanchez-Sanchez, 2021). Hence, a systematic review and meta-analysis were conducted with the aim of presenting the effects of plyometric training on skill and physical performance in healthy tennis players (Deng et al., 2022). In line with that, this doctoral dissertation presents a review of the literature on the effect of various plyometric training programs on speed, agility, and explosive power in tennis (Table 3). In such analysis, a total of 17 studies were included, involving 559 tennis players, with the smallest sample size in one study being 16, and the largest 64 participants. The majority of participants were male, while one study did not report the gender of the participants. The age of participants ranged from 11 to 25 years, with most having more than 2 years of tennis experience and being at the national level. As for the characteristics of the programs, in most of the studies, the number of training sessions ranged from 2 to 3 times per week. The duration varied from 20 to 60 minutes, while the entire plyometric training programs lasted from 6 to 8 weeks in almost all studies. Further in the text, the results will be described in more detail regarding the grouping of participants and the measured tests.

Gelen, Dede, Bingul, Bulgan, and Aydin (2012) noted an acute increase in maximal serve speed by 1-3% in the experimental dynamic and plyometric training group compared to the control group among elite players with over 8 years of tennis experience. Similar results with a comparable sample were obtained by Behringer, Neuerburg, Matthews, and Mester (2013), where they found that after a plyometric training program, serve speed increased by 3% compared to the resistance training program and control group where there was no increase. Additionally, Olcucu, Erdil, and Altinkok (2013) studied slightly older participants (20-25) with unreported tennis experience and compared plyometric training with basic conditioning, revealing significant positive effects on maximal serve velocity for 15%. However, Fernandez-Fernandez et al. (2018) and Fernandez-Fernandez et al. (2020) found somewhat different results in their research. They discovered that on a sample of young tennis players aged 12 to 15 years, after 8 weeks of neuromuscular training with various dominant plyometric exercises, there were no statistically significant improvements in serve velocity.

When discussing plyometric training and speed, Salonikidis and Zafeiridis (2008) found a significant improvement ($p < 0.05$) of 3-9% in the 4m and 12m side and forward sprints for both the combined group (plyometric training + tennis drills) and the plyometric training group alone. However, slightly better results were shown in the combined group. Regarding speed-related aspects, the same study established a positive impact ($p < 0.05$) of plyometric training on reaction time by as much as 27%. It is notable that the sample consisted of amateur (novice) level players, and it would certainly be interesting to conduct such research with more experienced tennis players. One of the studies involving elite players was conducted by Fernandez-Fernandez, Sanz-Rivas, Kovacs, and Moya (2015), where they found that explosive strength and repeated sprint training over 8 weeks improved results in the 10m sprint test and the repeated sprint test by approximately 3%. However, no difference was observed in longer sprint distances (20m and 30m). On the other hand, the same authors Fernandez-Fernandez et al. (2016) found, on a younger (13 years old) and less experienced sample, that a plyometric training program over 8 weeks could significantly improve results in shorter sprint distances (5m and 10m) by 3-10%. A positive impact of plyometric training on sprints (5m, 10m, 20m, 50m) was also found in other studies (Fernandez-Fernandez et al., 2018; Mohanta, Kalra, and Pawaria, 2019; Fernandez-Fernandez et al., 2020; Kanabar, Gajjar, and Patel, 2022). In all the mentioned studies, a similar sample was used, with participants having at least 2 years of tennis experience. The plyometric training program included 2-3 sessions per week for 6-8 weeks. The greatest impact of the plyometric training program was shown in the study by Gamlath and Thotawaththa (2023), where the result in the 10m sprint test increased by 19%. One reason for the program's success may be the frequency of training, which was 3 times per week, and the fact that the participants were slightly older (16-17 years) but with unreported experience and level of play. Additionally, Novak, Lončar, Sinković, Barbaros, and Milanović (2023) reported that a plyometric training program with a frequency of 2 times per week and a duration of 6 weeks did not significantly affect sprint tests at 5m, 10m, and 20m in tennis players aged 12-14 years. What is specific about this study and may have contributed to such results is the fact that the plyometric training program was not conducted in the traditional manner but rather with the use of resistance bands.

Few studies have delved into examining the effects of plyometric training on explosive power. In the case of upper extremity power, most studies have focused on assessing the effects of neuromuscular and plyometric training on performance in the medicine ball throw test (Fernandez-Fernandez et al., 2016; Fernandez-Fernandez et al., 2018; Fernandez-Fernandez et al., 2020). All of the mentioned studies had male participants with over 2 years of tennis experience and involvement at the national and international levels. The training frequency ranged from 2 to 3 times per week, and the duration of the programs in all studies was 8 weeks. Comparing the plyometric training program to the control group training, all studies showed statistically significant improvements in the medicine ball throw test, approximately up to 10%. When it comes to lower extremity power, the impact of plyometric training programs on horizontal and vertical jumps has been examined. Fernandez-Fernandez et al. (2015), on a sample of elite tennis players with over 8 years of tennis experience, found a positive impact of explosive strength and repeated sprint training on the countermovement jump (CMJ) after 8 weeks of implementation, with improvements ranging from 2% to 3%. Similar results were found by Fernandez-Fernandez et al. (2016) and Fernandez-Fernandez et al. (2020) on younger and less experienced tennis players, with improvements in countermovement jump ranging from 3% to 10% after 8 weeks of plyometric training. Additionally, Novak et al. (2023) in their study demonstrated a positive impact of plyometric exercises with resistance bands, conducted with a frequency of 2 times per week, lasting 30-45 minutes each session, over a duration of 6 weeks, on the countermovement jump and single-leg countermovement jump by 10-12%. Furthermore, Mohanta compared the difference between experimental plyometric training and circuit training on slightly older participants aged 18-25 years and found significant improvements in vertical jumps of more than 22% in both programs. From all of the mentioned studies, it is evident that each of them has shown significantly better results in vertical jumps, regardless of the variation in the participants' samples and program characteristics from study to study. It can be concluded that the greatest impact was obtained with slightly older participants who are more experienced and have a higher level of play. When discussing the impact of plyometric training on horizontal jumps, Barber-Westin et al. (2015) and Fernandez-Fernandez et al. (2016) on a sample of male and female tennis players of similar age (12-14 years) indicated that plyometric training, conducted 2-3 times a week for 8 weeks, led to improvements in tests such as the single-leg long jump and standing long jump (up to 10%).

Such results were also confirmed by Kanabar et al. (2017) in their study involving 40 male and female junior tennis players, where they found that both plyometric training and agility ladder training significantly positively influenced the performance in the standing long jump. In contrast, only Novak et al. (2023) established that there is no significant improvement in horizontal jump tests when it comes to the impact of plyometric training with resistance bands among participants aged 12-14 years at the national level of play.

One of the most important parts of this doctoral dissertation is the literature review related to the effect of plyometric training on agility performance in tennis players. The main problem lies in the fact that previous research has focused particularly on basic CODS tests and not on tests of reactive agility. In line with that, Fernandez-Fernandez et al. (2016) conducted a study with a sample of 60 male participants with international level of play and established statistically significant improvements (up to 10%) in the CODS 5-0-5 test after an 8-week plyometric training program. Similar results were found in the study by Fernandez-Fernandez et al. (2018) on the same sample of participants in terms of age (13 years), but with slightly higher tennis experience and level of play. It was found that neuromuscular training before tennis-specific training significantly influences the improvement in the performance of the CODS 5-0-5 test (up to 8%), while neuromuscular training after tennis-specific training did not show a significant impact on the same test. Fernandez-Fernandez et al. (2020) and Novak et al. (2023) also established that plyometric training does not have a statistically significant impact on the CODS 5-0-5 test and CODS T-test, after conducting plyometric training programs with resistance bands, but in a slightly shorter duration of 6 weeks. When it comes to some older participants (18-25 years) with no reported tennis experience and a lower level of play (amateur, college, and regional), it was found that an 8-week plyometric program with sessions lasting 30-60 minutes per session significantly improves results in the CODS T-test (>13%), Illinois test (11-13%), Hexagon test (22%), and Spider drill test (29%) (Rathore, 2016; Lakshmikanth et al., 2018; Ziagkas et al., 2019; Mohanta et al., 2019; Gamlath and Thotawaththa, 2023). When it comes to the effect of plyometric training on sport-specific newly constructed CODS and RAG tests, there are very limited number of studies on this topic. Barber-Westin (2015) examined a study with a sample of 42 male and female young tennis players (14.0 ± 2.0 years) with more than 2 years of training experience and found that a neuromuscular and performance training program significantly improved results in the new CODS Baseline and service box speed test. Furthermore, Lakshmikanth et al. (2018) in their study on slightly older participants (18-22 years) with undefined experience and lower playing level (college players) determined that a plyometric training program lasting 6 weeks with a frequency of only 1 training session per week significantly contributed to agility performances. In contrast to such findings, Novak et al. (2023) in their research on the effect of a plyometric program with resistance bands found that such training, conducted over the same duration of 6 weeks but with a slightly higher frequency (2 times per week), did not have a significant effect on improving results in agility test.

Based on the review of the literature, it can be concluded that most studies have indicated a positive effect of various plyometric training programs on serve velocity and some physical performance components (sprint speed, power and change of direction speed) for healthy tennis players. However, some limitations have been observed, which require further and new investigation into this topic in tennis. When it comes to population characteristics, it is evident that most studies have focused only on male participants, with only a few including participants of both genders. Since this doctoral dissertation also encompasses such a sample, it would be interesting to conduct a similar study with senior female tennis players. Additionally, there is considerable variation in the age range of participants, ranging from 11 to 25 years. Specifically, almost all studies include participants older than 15-16 years, so it is necessary to conduct new studies with a younger population in the developmental stage. Furthermore, tennis experience and level of play vary from amateur (novice) players to professional (elite) players competing at the international level. Regarding experimental characteristics, it is noticeable that programs differ in terms of frequency, time, and length. These characteristics vary from 1-3 training sessions per week, 20-60 minutes of training time, and 6-8 weeks in length. Accordingly, it is important to develop a new program within this range of characteristics that could have a greater impact on players' abilities compared to previous programs. It is also important to note that many studies have not reported some of these program characteristics, which is crucial for the validity of plyometric training success. The biggest issue arises when it comes to the tests used to demonstrate the effectiveness of a program. None of the studies have shown the impact of plyometric training programs on the anthropometric characteristics of tennis players. Additionally, when it comes to vertical and horizontal power tests, most studies have included a very limited number of tests, which typically consist of the countermovement jump test, vertical jump, and standing long jump tests. While the countermovement jump test and vertical jump test are essential and widely used for assessing lower body power, incorporating a greater variety of tests, like the triple jump test, squat jump test, and one-leg countermovement jump test, can provide a more comprehensive and sport-specific evaluation. These additional tests can reveal different facets of an athlete's power, coordination, and balance, leading to better training decisions and improved athletic performance. Specifically, the triple jump test assesses not only power but also coordination and the ability to generate power sequentially through multiple phases of movement. Additionally, one-leg tests can help identify asymmetries between the left and right legs, which is critical for injury prevention and balanced athletic development. Therefore, expanding the range of tests used in research and practice can offer significant benefits, particularly in sports like tennis where varied movement patterns are critical. Furthermore, a noticeable and crucial aspect of this doctoral dissertation is the lack of research on the effect of plyometric training on newly constructed CODS and RAG tests. While some studies have shown the effect of this type of training on existing and basic CODS tests, only one study presents the effect of a plyometric training program on a RAG performance (WS-S test). It is also important to note that this study did not show a significant impact on RAG and used resistance bands as aids, which can lead to varying results. Consequently, it is important to require further and new investigations into this topic in tennis to accurately show the impact of plyometric training programs on newly constructed RAG tests.

Based on all of the above, one of the aims of this doctoral dissertation is to demonstrate the effect of a six-week plyometric training program on sport-specific motor abilities, change of direction speed and reactive agility in young tennis players. The assumption is that such a training program will have a statistically significant impact on improving results in CODS and RAG performances.

Research aims and questions

The primary issue with newly developed CODS tests in tennis is their reliance on slight modifications of existing assessments, primarily altering the number of changes of direction and angles of movement with undefined validity measures. However, an even greater problem arises with the construction of new RAG tests, where only a few options exist but with shortcomings including undefined reliability and validity measures, a lack of reported participant characteristics, complicated stimulus positions, the influence of human factors, and tasks like the imitation of hitting a ball, which are likely to be less intentional than hitting a real tennis ball. In terms of correlations between speed, agility, and power, it is evident that the results vary across different types of basic CODS tests, and none of these correlations were examined with newly constructed CODS tests. However, an even more significant problem arises with the correlation between speed, agility, and power with RAG tests, where none of the reported studies have explored the correlation between anthropometric characteristics and motor abilities with RAG tests. When it comes to the effect of plyometric training on newly constructed CODS and RAG tests, it is notable that there is a lack of research with a limited range of tests and the use of additional equipment, which can lead to varying results.

Therefore, the main purpose of this doctoral thesis is to design and evaluate specific tests, explore the correlation between anthropometric variables and motor abilities and assess the efficiency of training programs for the development of agility in tennis. This dissertation is designed according to the Scandinavian model and is divided into three distinct studies with related research questions and aims:

1) Does the newly constructed test for assessing change of direction speed and reactive agility have acceptable metric characteristics, more precisely, is it reliable and valid?

2) Is there a correlation between performance in basic motor tests and performance in newly constructed change of direction speed and reactive agility tests?

3) What is the effect of a six-week plyometric training program on sport-specific motor abilities, change of direction speed and reactive agility measured by specially newly constructed tests?

List of research studies

To address the aforementioned questions, this thesis comprises three studies, all of which have been published in peer-reviewed journals. The studies are listed in chronological order based on their date of submission:

1. **Sinković, F.,** Foretić, N., Novak, D. (2022). Reliability, Validity and Sensitivity of Newly Developed Tennis-Specific Reactive Agility Tests. *Sustainability*, *14*(20), 13321.

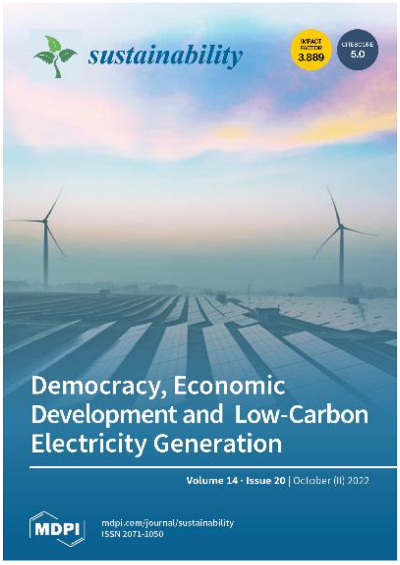
2. **Sinković, F.,** Novak, D., Foretić, N. (2023). The Association between Morphology, Speed, Power and Agility in Young Tennis Players. *Collegium Antropologicum*, *47*(1), 61-65.

3. **Sinković, F.,** Novak, D., Foretić, N., Kim, J., Subramanian, S.V. (2023). The plyometric treatment effects on change of direction speed and reactive agility in young tennis players: a randomized controlled trial. *Frontiers in Physiology*, *14*, 1226831.

ORIGINAL STUDIES

Study 1: Reliability, Validity and Sensitivity of Newly Developed Tennis-Specific Reactive Agility Tests

Sinković, F., Foretić, N., Novak, D. (2022). Reliability, Validity and Sensitivity of Newly Developed Tennis-Specific Reactive Agility Tests. *Sustainability*, *14*(20), 13321.



Sustainability, *14*(20), 13321

doi: 10.3390/su142013321

Manuscript submitted for publication: 7 September 2022

Manuscript accepted for publication: 12 October 2022

Indexed/Abstracted in: Scopus, SCIE and SSCI (Web of Science), GEOBASE, GeoRef, Inspec, AGRIS, RePEc, CAPlus, SciFinder and other databases

Journal impact factor: 3.889

ISSN: 2071-1050

sustainability

Article

Reliability, Validity and Sensitivity of Newly Developed Tennis-Specific Reactive Agility Tests

Filip Sinkovic [1], Nikola Foretic [2] and Dario Novak [1,*]

[1] Faculty of Kinesiology, University of Zagreb, 10000 Zagreb, Croatia
[2] Faculty of Kinesiology, University of Split, 21000 Split, Croatia
* Correspondence: dario.novak@kif.hr

Abstract: Agility is one of the motor skills on which success in tennis performance depends, and the aim of this research was the development and validation of a new test for assessing preplanned and reactive agility in young tennis players. The sample of respondents comprised 50 young competitors with an average age of 12.34 ± 1.22 years who were ranked up to 50th in the national tennis association ranking and up to 300th in the international Tennis Europe ranking. Agility variables were measured with newly constructed tests for the assessment of preplanned agility (CODS) and reactive agility (RAG), which were constructed in such a way that subjects imitated specific movements in tennis. It can be concluded that the newly constructed tests of preplanned agility (CODS) and reactive agility (RAG) have a high degree of reliability. Additionally, the assumption that the reliability will be slightly higher for preplanned agility tests (CA = 0.92 and 0.92; ICC = 0.86 and 0.82) than for reactive agility tests (CA = 0.90 and 0, 89; ICC = 0.74 and 0.72) was proven to be accurate. The results also showed that the tests have satisfactory validity. Thus, the results of both tests show a good correlation (p = 0.6 and p = 0.55) with the T-test of agility. It can be noted that all measurements, that is, all results, are normally distributed and that the values of skewness and kurtosis are within acceptable limits. We can confirm satisfactory sensitivity and their applicability to the sample of young tennis players. In conclusion, the results of this research confirmed the hypothesis and showed that the newly constructed agility tests have extremely good metric characteristics, especially the reactive agility test. Thus, this paper proposed a new procedure for the assessment of preplanned and reactive agility in young tennis players, which will significantly improve and advance the existing procedures, and make the results more reliable and precise.

Keywords: agility; speed; young tennis players; reliability; validity; sensitivity

Citation: Sinkovic, F.; Foretic, N.; Novak, D. Reliability, Validity and Sensitivity of Newly Developed Tennis-Specific Reactive Agility Tests. *Sustainability* **2022**, *14*, 13321. https://doi.org/10.3390/su142013321

Academic Editor: Franklin G. Mixon

Received: 7 September 2022
Accepted: 12 October 2022
Published: 17 October 2022

1. Introduction

Agility is considered one of the most important abilities for success in many sports, including tennis [1]. It is defined as a rapid whole-body movement with change of velocity and/or direction in response to a stimulus [2,3]. The great impact of agility on the achievement of top sports results has been confirmed in numerous studies [3–5]. There are two relatively independent manifested forms of agility. The first is nonreactive or preplanned agility (change of direction speed-CODS), which is characterized by a change in the direction of movement that is already known in advance; that is, it is planned, and the players do not need to react to a specific stimulus. The second form of agility is reactive or unplanned agility (Reactive agility-RAG), which includes a cognitive component, i.e., observation and decision-making factors [6–8].

In tennis, players very often change the direction of movement, so planned and reactive agility are considered extremely important motor dimensions [9,10]. Despite the importance of agility in tennis, there is very little scientific research that has dealt with this motor dimension, especially in specific conditions. An underlying problem in this lack of research is the lack of adequate tests; therefore, there has been an increasingly pronounced trend of constructing and validating new ones. To date, agility in tennis has mostly been measured with standardized basic tests, but this research will offer a new specific agility test. Studies whose primary goal is the construction of new sport-specific tests for agility assessment are usually based on the modification of already existing basic agility tests such as "*T*-test", "505 test", or the "Spider drill test" [11]. The disadvantage is that all the aforementioned tests were created to measure agility in which changes in the direction of movement are planned in advance. That is another important reason why is it necessary to develop a sport-specific test that assesses reactive agility, which is key to success in tennis. Reactive agility is manifested in conditions when a person needs to perform an agile movement structure but in such a way that it must react to some kind of stimulus. Most often in the area of reactive agility, the stimulus is actually a visual stimulus, which is completely clear because athletes perform agile movements based on the visual observations of either the opponent's movement or the trajectory of the ball. So, from this it can be concluded how reactive agility includes a cognitive component, i.e., the factors of observation and enactment of a decision to some stimulus that cannot be assessed by older agility tests. Everything mentioned above leads to the conclusion that the newly constructed test in this research will be able to better and more precisely measure agility compared to already known basic tests. For the newly constructed test to be usable it must have good metric characteristics, and this primarily refers to reliability and validity [11]. Sports-specific tests provide more detailed information about the real state of those traits and abilities that ultimately ensure the success of the player at the top level of competition [12]. Additionally, such tests always better describe the efficiency of the player's motor skills related to technical performance than is the case with basic tests [13]. In previous years, the specificity of sports conditioned an increasing number of developed protocols for assessing preplanned and reactive agility that include movements characteristic of a particular sport. In their research, Sekulić et al. developed a reliable and valid test for assessing predicted and reactive agility in futsal players on a sample of 30 subjects [6,10,12]. In addition to futsal, protocols have been developed for validating specific tests to assess planned and reactive agility on a sample of soccer players [13,14] and basketball players [15].

Since agility is one of the motor skills on which the success in tennis performance depends, the aim of this research was to develop and validate a new test for assessing preplanned and reactive agility in young tennis players. The assumption was that the newly constructed test would be reliable and valid and as such would be applicable to the sample of young tennis players. Using the newly constructed test, it should be possible to systematically develop training methods, as well as diagnostics, to enable tennis players to develop better and faster towards the top level of tennis.

2. Materials and Methods

2.1. Participants

Participants included in this study were 50 young tennis players with an average age of 12.34 ± 1.22 years, height 156.7 ± 12.85 cm and weighing 45.87 ± 8.87 kg ranked up to 50th in the national Tennis Federation ranking and up to 300th in the international Tennis Europe rankings. G-Power program was used to estimate the appropriate number of subjects (version 3.1.9.2; Heinrich Heine University, Dusseldorf, Germany). To participate in the study, all subjects had to meet the criteria that they were healthy, physically active players who trained at least three times a week and compete in regional, national, or international tournaments. The research was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Kinesiology of the University of Zagreb (protocol code 34; date of approval 13 December 2021). All participants were informed about the subject and goal of the study, and the subjects and their parents gave written consent to participate. The complete testing protocol was explained to them in detail with special emphasis on the fact that study requires certain additional effort and presents a risk of injury that is the same as during the standard training process or competition.

2.2. Measurements

Agility variables were measured with newly constructed tests for the assessment of preplanned agility (CODS) and reactive agility (RAG). The tests were measured using the Sportreact system (Sportreact, Zagreb, Croatia). The generic tennis agility test *T*-test was used to validate the mentioned tests. The *T*-test is considered the gold standard for measuring agility in tennis and includes forward, sideways and backward sprints.

2.3. Study Design and Procedure

The preplanned agility (CODS) and reactive agility (RAG) tests were constructed in such a way that the examinees imitated specific movements in tennis (Figure 1). The examinees start from a predetermined starting line in both tests. At the moment when the infrared signal (IR1) located next to the starting line is interrupted by the "split step", the time starts to be measured and one of the two lights (L1 or L2) lights up. The participant should recognize which light has turned on, run with an overstepping and lateral technique to the side to the stand with a ball placed on it (S1 or S2) and hit the aforementioned ball forehand or backhand in front of the body with enough force that the ball hits the ground. After playing the shot, the player should return as quickly as possible to the device in front of the starting line and interrupt the infrared signal (IR2) again, which ends the measurement. In the preplanned agility test (CODS), the subjects know in advance which light will turn on; that is, they can plan in advance to run and play forehand or backhand shots. Each test was performed nine times, and for further processing, the mean measured value of both tests was taken [14].

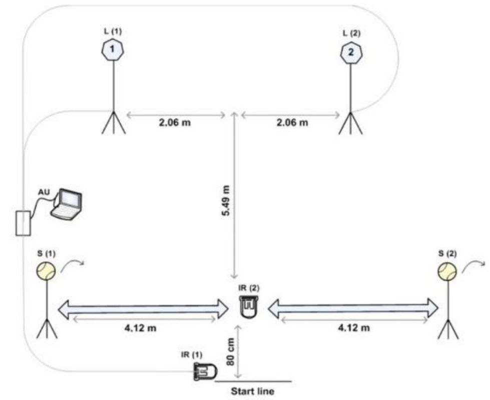


Figure 1. CODS and RAG test.

2.4. Statistical Analysis

Based on the collected data, the hypothesis was tested. The obtained data were processed in Statistica 13 for the Windows operating system and in Microsoft Excel 2013 (Palo Alto, CA, USA). Parameters that were calculated for quantitative variables consist of: arithmetic mean (AS), standard deviation (SD), minimum score (MIN), maximum score (MAX), measure of asymmetry (skewness) and measure of flatness (kurtosis). The normality of the distribution was tested with the Kolmogorov–Smirnov test. The reliability of the test was checked by calculating the Cronbach's alpha (CA) parameter and the intraclass correlation coefficient (ICC). The validity of the test was carried out through a set of correlation analyses, by calculating the Pearson's correlation coefficient. A set of factor analyzes with varimax rotation was calculated to determine the existence of latent dimensions and finally define the construct validity of the test. All conclusions are drawn at the level of statistical error of 5%.

3. Results

3.1. Reliability

Table 1 shows the reliability parameters for the newly constructed tests of planned agility (CODS) and reactive agility (RAG) in tennis.

Table 1. Reliability of CODS and RAG tests.

	CA (α)	ICC
CODS (R)	0.92	0.86
CODS (L)	0.92	0.82
RAG (R)	0.90	0.74
RAG (L)	0.89	0.72

CODS (R)—preplanned agility test to the right side; CODS (L)—preplanned agility test to the left side; RAG (R)—reactive agility test to the right side; RAG (L)—reactive agility test to the left side; CA—Cronbach Alpha reliability coefficient; ICC—intraclass correlation coefficient.

Based on the obtained results presented in Table 1, it can be concluded that the newly constructed tests of preplanned agility (CODS) and reactive agility (RAG) have a high degree of reliability. We also assumed that the reliability would be slightly higher for the preplanned agility tests (CA = 0.92 and 0.92; ICC = 0.86 and 0.82) than for the reactive agility tests (CA = 0.90 and 0,89; ICC = 0.74 and 0.72).

3.2. Validity

Table 2 shows the validity parameters for the newly constructed tests of preplanned agility (CODS) and reactive agility (RAG) in tennis. The validity of the test was carried out through a set of correlation analyses, by calculating the Pearson correlation coefficient, and the tennis agility *T*-test, which is considered the gold standard for measuring agility in tennis, was used to compare the results.

Table 2. Validity of CODS and RAG tests.

	T-TEST (AM)
CODS (AM)	$p = 0.55$
RAG (AM)	$p = 0.60$

CODS (AM)—arithmetic mean of preplanned agility test results; RAG (AM)—arithmetic mean of reactive agility test results; *T*-TEST (AM)—arithmetic mean of *T*-test agility test results; *p*—statistically significant association between tests.

Based on the obtained results presented in Table 2, it can be concluded that the newly constructed tests of preplanned agility (CODS) and reactive agility (RAG) have satisfactory validity. The results of both tests show good correlation ($p = 0.6$ and $p = 0.55$) with the agility *T*-test. This confirms the assumption that subjects who achieve better results on tests of preplanned agility (CODS) and reactive agility (RAG) will, with a high probability, achieve better results on the *T*-test of agility.

3.3. Sensitivity

Table 3 shows the descriptive parameters for the newly constructed tests of preplanned agility (CODS) and reactive agility (RAG) in tennis. The following were calculated: arithmetic mean (AM), standard deviation (SD), minimum score (MIN), maximum score (MAX), measure of asymmetry (SKEW) and measure of flatness (KURT) and the maximum difference between the values of the Kolmogorov–Smirnov test (MAX D).

Table 3. Descriptive parameters for CODS and RAG tests.

	AM	SD	MIN	MAX	SKEW	KURT	MAX D
CODS (R)	3.18	0.21	2.77	3.42	0.81	0.25	0.15
CODS (L)	3.18	0.16	2.83	3.79	0.65	0.60	0.12
RAG (R)	3.36	0.23	2.94	4.17	0.80	1.75	0.13
RAG (L)	3.37	0.23	2.96	4.04	0.73	0.93	0.12

According to the obtained results, it can be noted that all results are normally distributed. It is noticeable that there are no significant differences between the obtained normal distributions of the results given that none of the obtained values on the Kolmogorov–Smirnov test exceeds the limit value. Skewness and kurtosis values are also within acceptable limits. Therefore, based on the results shown in Table 3, we can speak about the satisfactory sensitivity of these newly constructed tests and their applicability to a sample of young tennis players.

4. Discussion

With the development of sports science, an increasing number of studies appeared that were concerned with determining the reliability of tests for the assessment of preplanned and reactive agility. Most often, these are sport-specific tests, which by their structure try to get as close as possible to certain situations within the chosen sport. Such research was conducted with samples of Australian football players [16], rugby players [17], netball players [18], basketball players [9,15], soccer player [13,14,19], futsal players [6,10,12,20]. Common to all the mentioned studies is that relatively high reliability of the analyzed tests was obtained, which makes the results obtained here expected. There is an advantage in the application of sport-specific tests compared with tests of a general character in the fact that during their performance, there are demands for knowledge of the technique of the individual sport, or specific movement structures for that sport [21]. Based on the above, the assumption is that sport-specific tests give a better insight into the actual state of sports form, and enable the differentiation of athletes on the basis of small differences that exist in them at the top level of competition. An additional difficulty in the application of sport-specific tests is the fact that they have not been systematically researched, so lack of them is evident both for tennis and other sports. What is important to emphasize is that the new tests were mainly based on the modification of already existing basic tests of agility such as "*T*-test", "505 test", "Spider drill test", and the disadvantage of such tests is that the changes of direction of movements were planned in advance [11]. From this, it can be concluded that the newly constructed test will be able to better and more precisely measure agility compared to already known basic tests.

In this research, the newly constructed tests showed extremely good metric characteristics. The high reliability of the tests can be attributed to the relatively short duration of the tests and their relatively simple execution. If we compare the results obtained here with each other, we can notice that the reliability obtained in the preplanned activity test (CA = 0.92 and 0.92; ICC = 0.86 and 0.82) is slightly higher than in the reactive agility test (CA = 0, 90 and 0.89; ICC = 0.74 and 0.72). The same trend of decreased reliability in the reactive component compared with preplanned agility was confirmed in the research of Sekulić et al., who aimed to construct a sport-specific test for assessing agility in basketball [9]. The reasons for the greater reliability of preplanned agility tests come down to the simple fact that such tests are less susceptible to error during execution. In tests of reactive agility, due to the greater demand on reaction speed, a greater number of errors occur in the form of violation of movement technique and incorrect selection of sides, which in itself leads to a decrease in the reliability of the test. Regardless of the fact that the reliability of the reactive agility test is somewhat weaker than that of preplanned agility, the results are still very satisfactory and show that the test as such will be applicable to a sample of young tennis players. The mentioned qualities are not easily and quickly trained, which makes reactive agility more complex and difficult to perform. Therefore, an athlete who possesses high-quality visual space scanning and anticipation will achieve better results on reactive agility tests [3]. This phenomenon has already been described in the literature in other sports. For example, Foretić et al. found differentially weak results on specific tests of reactive agility in young soccer players [22]. Pehar et al. showed the difference between preplanned and reactive agility in professional basketball players in all playing positions [23], and in the research of reactive agility on male and female handball players, it was determined that both genders achieve weaker results in the reactive agility test [24].

This study has a number of limitations that will be discussed below. Firstly, the subjects involved in this study were highly selected youth tennis players in a very sensitive and crucial developmental phase. Secondly, we did not evaluate the quality of the movement of the participants, which could influence movement performance; thirdly, we did not have the possibility to look at the mental and physical fatigue that may have occurred during the testing process, which could have potentially affected the most effective movement execution.

In summary, the present study confirmed that the newly constructed agility tests have good metric characteristics, especially the reactive agility test. Our findings provide useful information for coaches to create a wide range of tennis-specific situations to test proper movement, especially for their player's reactive agility. Therefore, the measurement of the reactive agility is suggested in the testing session of junior tennis players.

5. Conclusions

The results of this research confirmed the hypothesis and showed that the newly constructed agility tests have extremely good metric characteristics, especially the reactive agility test. This study proposed a new procedure for the assessment of preplanned and reactive agility in young tennis players, which will significantly improve and advance the existing procedures and make the results more reliable and precise. The shortcoming of this research is that the newly constructed tests were conducted with a convenient sample of subjects under controlled conditions, and the results might have been different if the tests had been conducted on a different sample of participants or in different conditions. The aim of future research should be to conduct tests with subjects of different genders and different competition categories in order to obtain the best and most precise data that would enable an even greater practical and scientific contribution.

Author Contributions: Conceptualization, D.N. and F.S.; methodology, F.S.; software, F.S.; validation, D.N., N.F. and F.S.; formal analysis, D.N.; investigation, F.S.; resources, D.N.; data curation, N.F.; writing—original draft preparation, F.S.; writing—review and editing, D.N.; visualization, N.F.; supervision, D.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Croatian Science Foundation (grant number IP-2018-01-8330).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Faculty of Kinesiology University of Zagreb (protocol code 34; date of approval 13 December 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data available on request.

Acknowledgments: The authors would like to thank the athletes for their willingness to participate in this investigation.

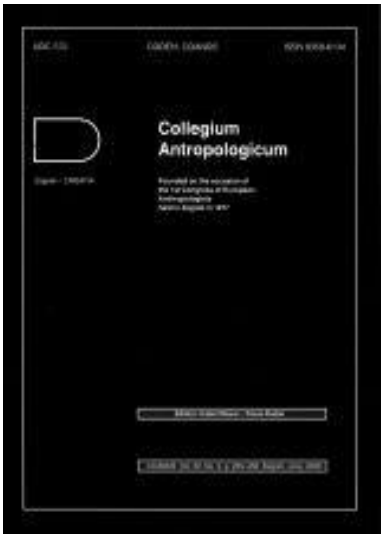
Conflicts of Interest: The authors declare no conflict of interest.

References

1. Paul, D.J.; Gabbett, T.J.; Nassis, G.P. Agility in team sports: Testing, training and factors affecting performance. *Sports Med.* **2016**, *46*, 421–442. [CrossRef] [PubMed]
2. Sekulić, D.; Metikoš, D. *Osnove Transformacijskih Postupaka u Kineziologiji: Uvod u Osnovne Kineziološke Transformacije Split*; Fakultet Prirodoslovno-Matematičkih Znanosti i Kineziologije: Split, Croatia, 2007.
3. Sheppard, J.M.; Young, W.B. Agility literature review: Classifications, training and testing. *J. Sports Sci.* **2006**, *24*, 919–932. [CrossRef] [PubMed]
4. Bompa, T.; Haff, G. *Periodization: Theory and Methodology of Training*, 5th ed.; Human Kinetics: Leeds, UK, 2009.
5. Lockie, R.G.; Jeffriess, M.D.; McGann, T.S.; Callaghan, S.J.; Schultz, A.B. Planned and reactive agility performance in semiprofessional and amateur basketball players. *Int. J. Sports Physiol. Perform.* **2014**, *9*, 766–771. [CrossRef] [PubMed]
6. Zeljko, I.; Gilic, B.; Sekulic, D. Validity, reliability and correlates of futsal- specific pre-planned and non-planned agility testing protocols. *Kinesiol. Slov.* **2020**, *26*, 25–34.
7. Perić, I.; Spasić, M.; Novak, D.; Ostojić, S.; Sekulić, D. Pre-Planned and Non-Planned Agility in Patients Ongoing Rehabilitation after Knee Surgery: Design, Reliability and Validity of the Newly Developed Testing Protocols. *Diagnostics* **2021**, *11*, 146. [CrossRef]
8. Gabbett, T.; Benton, D. Reactive agility of rugby league players. *J. Sci. Med. Sport* **2009**, *12*, 212–214. [CrossRef]
9. Sekulić, D.; Pehar, M.; Krolo, A.; Spasic, M.; Uljevic, O.; Calleja-González, J.; Sattler, T. Evaluation of Basketball-Specific Agility: Applicability of Preplanned and Nonplanned Agility Performances for Differentiating Playing Positions and Playing Levels. *J. Strength Cond. Res.* **2017**, *31*, 2278–2288. [CrossRef] [PubMed]
10. Sekulić, D.; Zeljko, I.; Gilić, B. Measuring pre-planned and non-planned agility in futsal; applicability of the newly designed sport specific protocols. In Proceedings of the 17th Annual Scientific Conference of Montenegrin Sports Academy, Dubrovnik, Croatia, 2–5 April 2020.
11. Pojskic, H.; Pagaduan, J.; Uzicanin, E.; Separovic, V.; Spasic, M.; Foretic, N.; Sekulic, D. Reliability, Validity and Usefulness of a New Response Time Test for Agility-Based Sports: A Simple vs. Complex Motor Task. *J. Sports Sci. Med.* **2019**, *18*, 623–635.
12. Sekulić, D.; Foretić, N.; Gilić, B.; Esco, M.R.; Hammami, R.; Uljević, O.; Versić, S.; Spasić, M. Importance of Agility Performance in Professional Futsal Players; Reliability and Applicability of Newly Developed Testing Protocols. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3246. [CrossRef]
13. Gilić, B.; Uljević, O.; Tokić, A. Utjecaj morfoloških karakteristika i motoričkih sposobnosti na reaktivnu i nereaktivnu agilnost mladih nogometaša. In Proceedings of the Deveta Međunarodna Konferencija Sportske Nauke i Zdravlje, Banja Luka, Bosnia and Herzegovina, 15 March 2019; pp. 185–191.
14. Krolo, A.; Gilic, B.; Foretic, N.; Pojskic, H.; Hammami, R.; Spasic, M.; Uljevic, O.; Versic, S.; Sekulic, D. Agility Testing in Youth Football (Soccer) Players; Evaluating Reliability, Validity, and Correlates of Newly Developed Testing Protocols. *Int. J. Environ. Res. Public Health* **2020**, *17*, 294. [CrossRef] [PubMed]
15. Pavlinović, V.; Spasić, M.; Foretić, Š.; Šišić, N. Validation of sport-specific agility tests for junior basketball players. *Tuzla* **2021**, *1*, 343–349.
16. Henry, G.J.; Dawson, B.; Lay, B.S.; Young, W.B. Decision-making accuracy in reactive agility: Quantifying the cost of poor decisions. *J. Strength Cond. Res.* **2013**, *27*, 3190–3196. [CrossRef] [PubMed]
17. Green, B.S.; Blake, C.; Caulfield, B.M. A valid field test protocol of linear speed and agility in rugby union. *J. Strength Cond. Res.* **2011**, *25*, 1256–1262. [CrossRef]
18. 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*, 52–60. [CrossRef]
19. Knoop, M.; Fernandez-Fernandez, J.; Ferrauti, A. Evaluation of a specific reaction and action speed test for the soccer goalkeeper. *J. Strength Cond. Res.* **2013**, *27*, 2141–2148. [CrossRef]
20. Benvenuti, C.; Minganti, C.; Condello, G.; Capranica, L.; Tessitore, A. Agility assessment in female futsal and soccer players. *Medicina* **2010**, *46*, 415–420. [CrossRef] [PubMed]
21. Sattler, T.; Sekulić, D.; Spasić, M.; Perić, M.; Krolo, A.; Uljević, O.; Kondrič, M. Analysis of the Association Between Motor and Anthropometric Variables with Change of Direction Speed and Reactive Agility Performance. *J. Hum. Kinet.* **2015**, *47*, 137–145. [CrossRef] [PubMed]
22. Foretić, N.; Spasić, M.; Radić, M. Pozicijske razlike u reaktivnoj i nereaktivnoj agilnosti mladih nogometaša. In Proceedings of the Deveta Međunarodna Konferencija Sportske Nauke i Zdravlje, Banja Luka, Bosnia and Herzegovina, 15 March 2019; pp. 179–184.
23. Pehar, M.; Uljević, O.; Foretić, N. Razlike u reaktivnoj i nereaktivnoj agilnosti između pet igračkih pozicija kod vrhunskih košarkaša. In Proceedings of the 11th Međunarodni Simpozijum Sport i Zdravlje, Tuzla, Bosnia and Herzegovina, 30 November 2018; pp. 50–54.
24. Spasic, M.; Krolo, A.; Zenic, N.; Delextrat, A.; Sekulic, D. Reactive Agility Performance in Handball; Development and Evaluation of a Sport-Specific Measurement Protocol. *J. Sports Sci. Med.* **2015**, *14*, 501–506. [PubMed]

Study 2: The Association between Morphology, Speed, Power and Agility in Young Tennis Players

Sinković, F., Novak, D., Foretić, N. (2023). The Association between Morphology, Speed, Power and Agility in Young Tennis Players. *Collegium Antropologicum, 47*(1), 61-65.



Collegium Antropologicum, *47*(1), 61-65

doi:10.5671/ca.47.1.8

Manuscript submitted for publication: 6 January 2023

Manuscript accepted for publication: 29 July 2023

Indexed/Abstracted in: Scopus, GEOBASE, GeoRef, Inspec, AGRIS, RePEc, CAPlus, SciFinder and other databases

Print ISSN: 0350-6134

Online ISSN: 1848-9486

Coll. Antropol. 47 (2023) 1: 61–65
Original scientific paper
doi:10.5671/ca.47.1.8

The Association Between Morphology, Speed, Power and Agility in Young Tennis Players

Filip Sinković[1], Dario Novak[1] Nikola Foretić[2]

[1]University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia
[2]University of Split, Faculty of Kinesiology, Split, Croatia

ABSTRACT

The aim of this study was to investigate the correlation of anthropometric variables and motor abilities in change of direction speed and reactive agility performance in young tennis players. 50 tennis players (age 12.3 ± 1.2 years, height 156.7 ± 12.8 cm, body mass 45.9 ± 8.9 kg), who were ranked within the top 50 ranking places of the National Tennis Association, as well as within the top 300 on the international "Tennis Europe" rankings, participated in the study. The sample of anthropometric variables in this study comprised the measurement of participant height, body mass, body mass index and percentage of body fat. Also, participants performed tests assessing speed (5, 10, and 20 m sprints), agility (20 yards, 4x10 yards, T–test, TENCODS, and TENRAG), and explosive power (countermovement jump, single-leg countermovement jump, squat jump, standing long jump and single-leg triple jump). The results showed that there is a statistically significant correlation of agility with anthropometric characteristics, running speed tests and horizontal explosive power variables, whereas there was no significant correlation with vertical explosive power variables. In conclusion, the results of this research confirmed the hypothesis that there is a significant correlation in almost all anthropometric variables and motor abilities in change of direction speed and reactive agility performance in young tennis players. Thus, our findings provide useful information for coaches to create a wide range of tennis-specific exercises to develop performance, especially in a players neuromuscular fitness.

Key words: *specific agility, neuromuscular fitness, physiological load, specific endurance, conditioning performance*

Introduction

Explosive speed has many properties, some of these being general speed, change of direction speed (CODS), and explosive power. These three aspects represent a key set of motor abilities that are proven to be very important for success in tennis. These abilities can be considered to be very similar, due to several common characteristics: they use the same energy resources, they stimulate the nervous system, and they meet the same prerequisites for intensive training of a particular motor ability[1]. In addition, it is considered that athletes with more pronounced explosive speed properties find it easier to control their body in urgent training and competition situations, subsequently contributing to not only their game, but also to the prevention of injuries[2].

A review of the literature shows that there are several studies that observe the correlations and effects of explosive speed properties in change of direction and reactive agility in soccer and futsal players.[3–5]. In these studies, a significant correlation between the effects of motor abilities on agility was determined. A greater impact was found in change of direction speed than reactive agility. It is obvious that reactive agility is affected not only by motor abilities, but also by many other cognitive factors such as observation, perception, anticipation, or speed of decision-making. Such results were also confirmed in previous research that indicated a significant connection between speed, explosiveness and certain morphological characteristics in agility performance in ball sports[6,7]. In tennis, players change their direction of movement very regularly, so change of direction speed and reactive agility are considered very important motor dimensions[8,9]. Regardless of the importance of agility in tennis, there is very little scientific research that has dealt with this motor dimension, especially in specific conditions. The basic problem for the lack of such research is related to the lack of adequate tests, and the trend of constructing and val-

Received for publication January 6, 2023

idating new one is becoming increasingly pronounced. Until now, agility in tennis has mostly been measured with standardized basic tests, however in this research, agility was measured with a newly constructed test that shows extremely good metric characteristics and gives valid and reliable results[10]. This is therefore one of the first studies that aims to investigate the correlations between anthropometric characteristics, speed, and explosive power variables in change of direction speed and reactive agility in tennis. Moreover, this research will answer whether the results achieved in basic motor tests affect the result in change of direction speed and reactive agility, with this being one of the most important abilities in tennis. With such knowledge, it is possible to predict the possible improvement of the tennis player's agility more reliably in regards to the improvement of other characteristics.

Considering these results and the previous lack of research in this area in relation to tennis, the aim of this paper is to investigate the correlation of anthropometric variables and motor abilities in change of direction speed and reactive agility performance in young tennis players. It is expected that there is a significant correlation of explosive speed properties in change of direction speed and reactive agility performance in young tennis players in the phase of pre-puberty and early puberty.

Materials and Methods

Participants

The sample included 50 young male tennis players (12.3 ± 1.2 years, height 156.7 ± 12.8 cm and weight 45.9 ± 8.9 kg), who were ranked within the top 50 of the National Tennis Association ranking, as well as in the top 300 on the international "Tennis Europe" rankings. The G-Power program (version 3.1.9.2; Heinrich Heine University, Dusseldorf, Germany) was used to estimate the appropriate number of participants. The inclusion criteria consisted of being in good health, and physically active players who train at least three times per week and compete in regional, national, or international tournaments. The exclusion criteria consisted of participants with any injury that influences their ability to play tennis as well as their physical performance. The research was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (protocol number 34; approval date December 13, 2021). All participants were familiar with the protocol and aim of the research prior to the study commencing, and both the participants and their parents gave prior written consent to participate. The complete testing protocol was explained to them in detail, with special emphasis on the fact that research requires a certain additional effort and presents a possible risk of injury, similar to any usual training session or competition.

Measurements

The sample of anthropometric variables in this study comprised of the measurement of participant height, body mass, body mass index (BMI) and percentage of body fat (%). Height (cm) and mass (kg) were assessed with a Seca stadiometer and a scale (Seca Instruments Ltd., Hamburg, Germany) using standard procedures, while body fat percentage (%) was measured using the MALTRON BF 900 analyser (Maltron International Ltd, Rayleigh, UK)[11]. Further, participants performed tests assessing speed (5, 10, and 20 m sprints), agility (20 yards, 4x10 yards, T–test, TENCODS, and TENRAG), and explosive power (countermovement jump (CMJ), single-leg countermovement jump (CMJ L,R), squat jump (SJ), standing long jump (L_JUMP) and single-leg triple jump (SLTJ_L,R). Speed was measured with Powertimer system photocells (Newtest Oy, Oulu, Finland), agility was measured with the SportReact system (SportReact, Zagreb, Croatia) and explosive power during jumps were measured with the Optojump system (Microgate, Bolzano, Italy). Each test was performed three times, and the mean value of three trials was taken for further processing.

Experimental protocol

The sport-specific change of direction speed (TENCODS) and reactive agility (TENRAG) variables were measured on clay tennis surface using tests that exhibit valid and reliable metric results[12]. The tests was conducted using the SportReact system (SportReact, Zagreb, Croatia) made up of laser tape sensors and LED screens with differing signs and colours[12]. The pre-planned ability to change direction (TENCODS) and reactive agility (TENRAG) tests were constructed in such a way that the participants imitate specific movements in tennis (Figure 1). In both tests, participants start from a predetermined starting line. When the infrared signal (IR1) located next to the starting line is interrupted by the "split step" the

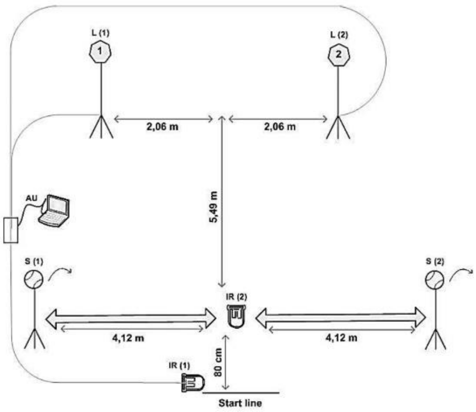


Fig. 1. TENCODS and TENRAG test.

participant performed, the clock began counting and one of the two lights (L1 or L2) lit up. The participants would recognize which light has turned on, run with overstepping and lateral technique to the side to the stand with a ball placed on it (S1 or S2) and hit the ball in a forehand or backhand motion with enough force for the ball to hit the ground. After playing the shot the player would return as quickly as possible to the device in front of the starting line and interrupt the infrared signal (IR2) again, which ended the timer. In the pre-planned change of direction speed test (TENCODS), the subjects would know in advance which light will turn on, meaning they can pre plan which direction to run in. Each test was performed nine times with a 60-second intermission between each measurement, and the mean measured value for both tests was taken for further processing[12].

Statistical Analysis

The obtained data was then processed in the program Statistica 14.0.1.25 (TIBCO software, Inc.) on the Windows operating system and in Microsoft Excel 2016 (Palo Alto, CA, USA). Basic descriptive parameters (mean—x̄; standard deviation—SD) were used to describe each variable. The normality of the distribution was tested with the Shapiro-Wilk W test. Correlation statistical analysis was used to investigate the correlation of anthropometric variables and motor abilities with change of direction speed and reactive agility performance. The level of statistical significance was set at $p < 0.05$.

TABLE 1

BASIC DESCRIPTIVE PARAMETERS (x̄ and SD)

Variables	x̄	SD
Body height (cm)	156.70	12.85
Body mass (kg)	45.87	8.87
Body mass index (BMI)	18.22	1.87
Body fat (%)	15.62	5.05
Sprint 5m (s)	1.26	0.06
Sprint 10m (s)	2.12	0.09
Sprint 20m (s)	3.74	0.18
CODS 4x10 yards (s)	10.55	0.56
CODS 20 yards (s)	5.60	0.30
CODS T-test (s)	12.14	0.67
Standing long jump (cm)	160.01	16.70
Triple jump_L (cm)	449.96	60.35
Triple jump_R (cm)	449.34	55.79
CMJ (cm)	22.58	3.29
SJ (cm)	22.20	3.66
CMJ_L (cm)	11.19	1.41
CMJ_R (cm)	11.31	1.31
TENCODS (s)	3.20	0.16
TENRAG (s)	3.36	0.16

CMJ (cm) – countermovement jump with arms set on hips; SJ (cm) – squat jump; CMJ_L (cm) – single leg (left) countermovement jump with arms set on hips; CMJ_R (cm) – single leg (right) countermovement jump with arms set on hips; TENCODS (s) – change of direction speed test; TENRAG (s) – reactive agility test; x̄ – mean; SD – standard deviation

Results

Table 1 shows the basic descriptive statistical parameters of anthropometric and motor ability variables. Arithmetic mean (x̄) and standard deviation (SD) were calculated for each variable mentioned. The Shapiro-Wilk W test showed a normal distribution, which enabled further statistical analysis. The agility tests showed that young tennis players achieve better results in preplanned motions of changing direction (3.20 ± 0.16 seconds) compared to reactive agility (3.36 ± 0.16 seconds).

Tables 2 and 3 show the results of a correlation analysis that established the correlation between anthropometric characteristics, running speed and explosive power with sport-specific pre-planned and reactive agility. Correlations between anthropometric and explosive speed variables with measures of preplanned and reactive agil-

TABLE 2

CORRELATIONS BETWEEN AGILITY AND MORPHOLOGY

Variables	TENCODS (s)	TENRAG (s)
Body height (cm)	–0.30*	–0.40*
Body mass (kg)	–0.30*	–0.41*
Body mass index (BMI)	–0.22	–0.30*
Body fat (%)	–0.08	–0.18

*significant correlation

TABLE 3

CORRELATIONS BETWEEN AGILITY, CODS AND EXPLOSIVE SPEED PROPERTIES

Variables	TENCODS (s)	TENRAG (s)
Sprint 5m (s)	0.45*	0.51*
Sprint 10m (s)	0.40*	0.33*
Sprint 20m (s)	0.51*	0.39*
CODS 4x10 yards (s)	0.47*	0.54*
CODS 20 yards (s)	0.47*	0.47*
CODS T-test (s)	0.56*	0.61*
Standing long jump (cm)	–0.39*	–0.21
Triple jump_L (cm)	–0.49*	–0.48*
Triple jump_R (cm)	–0.37*	–0.40*
CMJ (cm)	–0.27	–0.14
SJ (cm)	–0.25	–0.10
CMJ_L (cm)	–0.14	–-0.03
CMJ_R (cm)	–0.19	–0.09

CMJ (cm) - countermovement jump with arms set on hips; SJ (cm) - squat jump; CMJ_L (cm) - single leg (left) countermovement jump with arms set on hips; CMJ_R (cm) - single leg (right) countermovement jump with arms set on hips; TENCODS (s) – change of direction speed test; TENRAG (s) – reactive agility test; *—significant correlation ity were significant in almost all cases. The correlation is set in such a way that Pearson's correlation coefficient (r) of 0 – 0.29 represents a low correlation, from 0.30 – 0.63 a medium correlation, while 0.64 – 1 represents a high correlation. A significant correlation with pre-planned agility is noticeable in almost all measured variables, and we can conclude that the correlation is more significant on pre-planned agility than on reactive agility.

Discussion

The analysis of the results indicate two very important findings. Firstly, young tennis players achieve better results in pre-planned agility (3.20 ± 0.16 seconds) compared to reactive agility (3.36 ± 0.16 seconds). Secondly, there is a statistically significant correlation of agility with anthropometric characteristics, running speed tests and horizontal explosive power variables, while there is no statistically significant correlation with vertical explosive power variables. The reasons for better results in the preplanned agility tests comes down to the simple fact that in such tests there are no decision-making factors and the movement structure is known in advance, therefore the participants are less susceptible to the influence of errors during execution. On the other hand, the reactive agility test is considered more complex and difficult to perform due to the greater demand on reaction speed, and therefore it is logical that the result is likely to be worse. This unusual phenomenon has been reported in previous literature in relation to other sports, such as the weaker results in specific tests on reactive agility found in young soccer players[13]. Previous research has also shown the difference between pre-planned and reactive agility in professional basketball players in all playing positions[14]. In a sample of male and female handball players, it was determined that in both sexes, weaker results were recorded in the reactive agility test than in the preplanned agility tests[15].

The results of the correlation analysis show that the correlation of the analyzed anthropometric and explosive speed variables with measures of pre-planned and reactive agility is significant in almost all measured variables. It can therefore be said that there is an effect of some anthropometric characteristics and motor abilities on agility in general, with the fact that the effect is more significance on pre-planned agility. According to the results, it is obvious that reactive agility depends on a number of other factors. This is also indicated by previous research in which it is evident that the overall performance of reactive agility is more effected by cognitive factors, such as perception and decision-making as opposed to motor components[16–18]. In conclusion, the assumption was confirmed that young tennis players who achieve higher results in some anthropometric characteristics and motor ability tests are highly likely to achieve better results in the newly constructed tests of specific agility, especially CODS tests. Therefore, for future research it could be beneficial to determine the level of cognitive factors, perception, and decision-making in order to more precisely explain the effect and association between morphology, speed and power with reactive agility (RAG) in young tennis players.

The limitations of this study are discussed below. Firstly, the subjects involved in this study were young tennis players in a very sensitive and crucial phase of their developmental. Secondly, the study did not evaluate the biological age of the participants, which is known to have an influence on neuromuscular performance. Future research should be directed towards implementing tests with a larger number of participants in competitive conditions in order to obtain more data, and thus to enable explanations on the correlations of explosive speed properties in change of direction speed and reactive agility in younger tennis players during competitive performance. Also, another limitation to this research is that the motor tests were conducted with a convenient sample of subjects under controlled conditions, the results of which may have been different if the tests had been conducted on a different tennis surface. Therefore, although some causality can be intuitively identified (i.e., anthropometrics are predictors of change of direction speed), the true cause effect between conditioning abilities (i.e., sprinting speed and jumping capacities) should be more precisely studied through longitudinal investigations.

A more detailed analysis of the training volume (i.e., strength, endurance, and/or other qualities) would also help to clarify whether performance differences are also mediated by training. Another limitation was the lack of strength/power related measurements, of which would definitely help to determine whether the differences found herein are mediated by differences in the strength levels or in the ability to change direction rapidly. However, we believe that the present design may offer a starting point to suggest practical applications to tennis professionals. The gained insights from this research in practice could be for both tennis and fitness coaches to understand changes in the tested parameters during training processes. This can be used in planning and programming training loads in order to improve the aforementioned parameters.

Conclusion

The results of this research confirmed the hypothesis and showed that there is a significant correlation of anthropometric variables and motor abilities in change of direction speed and reactive agility performance in young tennis players. Thus, our findings provide useful information for coaches to create a wide range of tennis-specific situations to develop beneficial performance, especially for the player's neuromuscular fitness. A suggested aim for future research could be to conduct tests with subjects of differing genders and differing competition categories in order to obtain the best and most precise data that would enable an even greater practical and scientific understanding and application. Furthermore, a recommendation for additional research could be to determine the best training approaches and content (specific to each maturity stage) to meaningfully improve neuromuscular performance in young tennis players in the phase of both pre-puberty and early puberty.

Acknowledgments

The authors would like to thank the athletes for their willingness to participate in this investigation.

F. Sinković

Faculty of Kinesiology, University of Zagreb, Horvaćanski zavoj 15, 10000 Zagreb, Croatia
e-mail: filip.sinkovic@kif.unizg.hr

REFERENCES

1. PEARSON A, Speed, Agility and Quickness for Soccer (A&C Black, London, 2001). — 2. MILANOVIĆ L, BAŠIĆ M, MILANOVIĆ M, Razvoj brzinsko-eksplozivnih svojstava u tenisu (SAQ). In: FINDAK V, DELIJA K (Eds) Informatizacija u područjima edukacije, sporta i sportske rekreacije : zbornik radova (Hrvatski kineziološki savez, Zagreb, 2005). — 3. KROLO A, GILIC B, FORETIC N, Int J Environ Res Public Health, 17 (2020) 294. doi: 10.3390/ijerph17010294. — 4. GILIĆ B, ULJEVIĆ O, TOKIĆ A, Utjecaj morfoloških karakteristika i motoričkih sposobnosti na reaktivnu i nereaktivnu agilnost mladih nogometaša. In: BAJTIĆ O, NIĆI Đ (Eds) Deveta međunarodna konferencija sportske nauke i zdravlje (Panevropski univerzitet, Banja Luka, 2019). — 5. SATTLER T, SEKULIĆ D, SPASIĆ M, J Hum Kinet, 47 (2015) 137. doi:10.1515/hukin-2015-0069. — 6. GABBETT TJ, Br J Sports Med, 36 (2002) 334. doi:10.1136/bjsm.36.5.334. — 7. YOUNG WB, JAMES R, MONTGOMERY I, J Sports Med Phys Fitness, 42 (2002) 282. — 8. SEKULIĆ D, PEHAR M, KROLO A, SPASIC M, ULJEVIC O, CALLEJA-GONZÁLEZ J, SATTLER T, J Strength Cond Res, 31 (2017) 2278. doi: 10.1519/JSC.0000000000001646. — 9. SEKULIĆ D, ZELJKO I, GILIĆ B, Measuring pre-planned and non-planned agility in futsal; applicability of the newly designed sport specific protocols. In: BJELICA D, POPOVIĆ S (Eds) 17th Annual Scientific Conference of Montenegrin Sports Academy "Sport, Physical Activity and Health: Contemporary Perspectives" (Montenegro Sports Academy, Cavtat, 2020). — 10. POJSKIC H, PAGADUAN J, UZICANIN E, SEPAROVIC V, SPASIC M, FORETIC N, SEKULIC D, J Sports Sci Med, 18 (2019) 623. — 11. PERIC M, ZENIC N, MANDIC GF, SEKULIC D, SAJBER D, J Hum Kinet, 32 (2012) 135. doi: 10.2478/v10078-012-0030-8. — 12. SINKOVIC F, FORETIC N, NOVAK D, Sustainability, 14 (2022) 13321. — 13. FORETIĆ N, SPASIĆ M, RADIĆ M, Pozicijske razlike u reaktivnoj i nereaktivnoj agilnosti mladih nogometaša . In: BAJTIĆ O, NIĆI Đ (Eds) Deveta međunarodna konferencija sportske nauke i zdravlje (Panevropski univerzitet, Banja Luka, 2019). — 14. PEHAR M, ULJEVIĆ O, FORETIĆ N, Razlike u reaktivnoj i nereaktivnoj agilnosti između pet igračkih pozicija kod vrhunskih košarkaša. In: ŠEPAROVIĆ V (Ed) 11. Međunarodni simpozijum – sport i zdravlje – Zbornik radova (Sport University, Tuzla, 2018). — 15. SPASIC M, KROLO A, ZENIC N, DELEXTRAT A, SEKULIC D, J Sports Sci Med, 14 (2015) 501. — 16. GABBETT T, BENTON D, J Sci Med Sport, 12 (2009) 212. doi: 10.1016/j.jsams.2007.08.011. — 17. SCANLAN A, HUMPHRIES B, TUCKER PS, DALBO V, J Sports Sci, 32 (2014) 367. doi:10.1080/02640414.2013.825730. — 18. VESTBERG T, GUSTAFSON R, MAUREX L, INGVAR M, PETROVIC P, PLoS One, 7 (2012) 34731. doi:10.1371/journal.pone.003473.

POVEZANOST MORFOLOGIJE, BRZINE, SNAGE I AGILNOSTI KOD MLADIH TENISAČA

SAŽETAK

Cilj ovog istraživanja bio je istražiti povezanost antropometrijskih varijabli i motoričkih sposobnosti kod brzine s promjenom smjera kretanja i reaktivne agilnosti kod mladih tenisača. U istraživanju je sudjelovalo 50 tenisača (prosječne dobi 12,3 ± 1,2 godina, visine 156,7 ± 12,8 cm i tjelesne mase 45,9 ± 8,9 kg) koji su rangirani do 50. mjesta na ljestvici nacionalnog teniskog saveza, te do 300. mjesta na međunarodnoj „Tennis Europe" ljestvici. Uzorak antropometrijskih varijabli u ovom istraživanju sastojao se od mjerenja tjelesne visine, tjelesna mase, indeksa tjelesne mase i postotka potkožnog masnog tkiva ispitanika. Također, sudionici su izvodili testove za procjenu brzine (sprint na 5, 10 i 20 metara), agilnosti (20 jardi, 4x10 jardi, T–test, TENCODS i TENRAG) i eksplozivne snage (skok u vis iz mjesta, jednonožni skok u vis iz mjesta, skok iz čučnja, skok u dalj s mjesta i jednonožni troskok s mjesta). Rezultati su pokazali da postoji statistički značajna povezanost između agilnosti i antropometrijskih karakteristika, te testovima brzine trčanja i varijablama horizontalne eksplozivne snage, dok nije utvrđena značajna povezanost s varijablama vertikalne eksplozivne snage. Zaključno, rezultati ovog istraživanja potvrdili su hipotezu da postoji značajna povezanost kod gotovo svih antropometrijskih varijabli i motoričkih sposobnosti s rezultatima brzine s promjenom smjera kretanja i reaktivne agilnosti kod mladih tenisača. Stoga, navedene spoznaje predstavljaju korisne informacije za trenere kod pripreme širokog raspona vježbi specifičnih za tenis s ciljem poboljšanja izvedbe, posebno za neuromuskularne sposobnosti igrača.

Study 3: The plyometric treatment effects on change of direction speed and reactive agility in young tennis players: a randomized controlled trial

Sinković, F., Novak, D., Foretić, N., Kim, J., Subramanian, S.V. (2023). The plyometric treatment effects on change of direction speed and reactive agility in young tennis players: a randomized controlled trial. *Frontiers in Physiology*, *14*, 1226831.

Frontiers in Physiology, *14*, 1226831
doi: 10.3389/fphys.2023.1226831
Manuscript submitted for publication: 22 May 2023
Manuscript accepted for publication: 31 July 2023

Indexed/Abstracted in: PubMed, PubMed Central (PMC), Scopus, Web of Science Science Citation Index Expanded (SCIE), Google Scholar, DOAJ, CrossRef and other databases

Journal impact factor: 4.755

Online ISSN: 1664-042X

frontiers | Frontiers in Physiology

TYPE Original Research
PUBLISHED 08 August 2023
DOI 10.3389/fphys.2023.1226831

OPEN ACCESS

EDITED BY
Tomas Maly,
Charles University, Czechia

REVIEWED BY
Ghaith Aloui,
University of Manouba, Tunisia
Recep Soslu,
Karamanoğlu Mehmetbey University, Türkiye

*CORRESPONDENCE
Filip Sinkovic,
filip.sinkovic@kif.unizg.hr

RECEIVED 22 May 2023
ACCEPTED 31 July 2023
PUBLISHED 08 August 2023

CITATION
Sinkovic F, Novak D, Foretic N, Kim J and Subramanian SV (2023), The plyometric treatment effects on change of direction speed and reactive agility in young tennis players: a randomized controlled trial.
Front. Physiol. 14:1226831.
doi: 10.3389/fphys.2023.1226831

The plyometric treatment effects on change of direction speed and reactive agility in young tennis players: a randomized controlled trial

Filip Sinkovic[1]*, Dario Novak[1], Nikola Foretic[2], Jinseo Kim[3] and S. V. Subramanian[4,5]

[1]Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia, [2]Faculty of Kinesiology, University of Split, Split, Croatia, [3]Interdisciplinary Program in Precision Public Health, Department of Public Health Sciences, Graduate School of Korea University, Seoul, Republic of Korea, [4]Department of Social and Behavioral Sciences, Harvard T. H. Chan School of Public Health, Boston, MA, United States, [5]Harvard Center for Population and Development Studies, Cambridge, MA, United States

Aim: The aim of this paper is to determine the effect of 6 weeks of plyometric training on speed, explosive power, pre-planned agility, and reactive agility in young tennis players.

Methods: The participants in this study included 35 male tennis players (age 12.14 ± 1.3 years, height 157.35 ± 9.53 cm and body mass 45.84 ± 8.43 kg at the beginning of the experiment). The biological age was calculated and determined for all participants. 18 of the participants were randomly assigned to the control group, and 17 were assigned to the experimental group. Running speed (sprints at 5, 10, and 20 m), change of direction speed (4 × 10, 20 yards, *t*-test, TENCODS), reactive agility (TENRAG), and explosive power (long jump, single leg triple jump, countermovement jump, squat jump, and single leg countermovement jump) were all tested. The Mixed model (2 × 2) ANOVA was used to determine the interactions and influence of a training program on test results. Furthermore, Bonferroni *post hoc* test was performed on variables with significant time*group interactions.

Results: The results of this research indicate that an experimental training program affected results in a set time period, i.e. 5 out of total 15 variables showed significant improvement after experimental protocol when final testing was conducted. The experimental group showed significantly improved results in the 5 m sprint test in the final testing phase compared to the initial testing phase, this was also the case in comparison to the control group in both measurements. Furthermore, the experimental group showed significant improvement in the single leg countermovement jump in the final test, as well as in comparison to the control group in both measurements. The change of direction speed and reactive agility test also exhibited significant improvement in the final testing phase of the experimental group.

Conclusion: The results of this research indicated that a 6-week program dominated by plyometric training can have a significant effect on the improvement of specific motor abilities within younger competitive categories. These results offer valuable insights for coaches in designing diverse tennis-specific scenarios to enhance overall performance, particularly focusing on the neuromuscular fitness of their players.

KEYWORDS

tennis, specific agility, experimental protocol, neuromuscular training, motor abilities

1 Introduction

Tennis, as a complex activity, is characterized by a number of specific movement structures that alternate depending on the situation and predominantly require maximum speed over a given period of time (Milanović et al., 2005). Due to the reactive requirements of the game, the total duration of a match, the basis on which it is played and the energy consumption required during a match, it can be said that one of the main goals of training tennis players must be directed towards the development and maintenance of speed, agility and explosive power (Milanović et al., 2005). Pre-planned change of direction speed (CODS) is characterized by a change in the direction of movement that is already known in advance, it is planned and players do not need to react to a certain stimulus. On the other hand, reactive agility (RAG) includes cognitive processing, observational skills, and decision-making factors (Sekulić et al., 2017). In the area of RAG, players most often need to react to a visual stimulus, which is crucial in the field of sports since athletes usually perform agile movements based on visual observation of either the opponent's motion or the trajectory of the ball (Sekulić et al., 2020). Given that movement in tennis is highly specific, CODS and RAG are considered to be crucial motor abilities (Sekulić et al., 2017; Sekulić et al., 2020).

Regardless of the importance of CODS and RAG in tennis, there are only a few scientific studies dealing with these motor abilities, especially under specific conditions. So far, these abilities have mostly been measured by standardized basic tests. This study will use a reliable and valid tennis-specific change of direction speed test (TENCODS) and a tennis specific reactive agility test (TENRAG) under specific conditions (Sinkovic et al., 2022).

We are increasingly faced with the fact that conditioning training is effective even in the prepubescent phase (Čanaki and Birkić, 2009). Prepuberty should be seen as a time of early anatomical adjustment of the heart, lungs, joints, and muscles to prolonged physical activity (Čanaki and Birkić, 2009). This should serve as the foundation upon which athletes will build aerobic and anaerobic fitness during the specialization and peak performance phase (Čanaki and Birkić, 2009). Although prepubescent conditioning training must be approached with caution, it is clear that dedicating more time to the development ability of changing direction and agility during prepuberty and early puberty increases the chances of fully exploiting this ability's potential in later stages of sports development (Čanaki and Birkić, 2009). Additionally, it is important to adapt the plan and program of conditioning training during prepubescence and early puberty phases, specifically for the younger competitive categories of tennis players (U-12 and U-14).

Plyometric training offers the necessary stimuli for developing the stretch-shortening cycle (SSC) mechanism and has the potential to improve explosive contractions in both prepubertal and pubertal individuals (Fernandez-Fernandez et al., 2016). In other words, plyometric training focuses on combining strength with speed of movement to generate power (Fernandez-Fernandez et al., 2016). Nowadays, there is increasing exploration of the influence of plyometric training on motor abilities, as well as biomechanical and physiological parameters in tennis (Salonikidis and Zafeiridis, 2008; Kilit and Arslan, 2019). Literature reviews show that plyometric training has the potential to enhance maximal serve velocity and various physical performance components, such as sprint speed, lower extremity muscular power and agility among healthy tennis players (Davies et al., 2015; Novak et al., 2023). Nevertheless, further research is warranted to gather more high-quality evidence regarding the effects of plyometric training on the skill and physical performance of tennis players (Davies et al., 2015). Some studies suggest that regular use of plyometrics in tennis training for younger players has a significant impact on CODS tests (Antekolović et al., 2003; Vuong et al., 2022). The main challenge lies in the lack of appropriate testing mechanisms, as most of the CODS in tennis has been assessed using standardized basic tests or modifications of existing ones, such as the "*t*-test," "505 test," and "Spider drill test" (Sinkovic et al., 2022). Additionally, one of the main problems is the lack of research investigating the effect of plyometric training on CODS and RAG in young tennis players, this being something that this study aims to provide answers to. It has been found that CODS is the most influential factor for tennis performance and is strongly influenced by linear speed and jumping power (Vuong et al., 2022). Therefore, it can be concluded that the tests were primarily designed to measure pre-planned agility, where changes in movement direction are planned in advance. It is crucial to emphasize that this study will utilize a specific test to assess reactive agility, which is a key factor for success in tennis.

In accordance with the above, the aim of this paper is to determine the effect of two plyometric, explosive power, pre-planned agility, and reactive agility sessions per week for tennis players from the younger competition categories (U-12 and U-14) in prepuberty and early puberty.

2 Methods

2.1 Participants

The sample included 35 young male tennis players (age 12.14 ± 1.3 years, height 157.35 ± 9.53 cm and body mass 45.84 ± 8.43 kg at the beginning of the experiment) who were ranked in the top 50 in the National Tennis Association rankings, as well the top 300 on the international "Tennis Europe" rankings. The G-Power program (version 3.1.9.2; Heinrich Heine University, Dusseldorf, Germany) was used to estimate the appropriate number of participants, with an expected effect power of f = 0.33, an alpha level of 0.05, and a statistical power of 0.90. 18 participants were randomly assigned to the control group (CG), and 17 participants were assigned to the

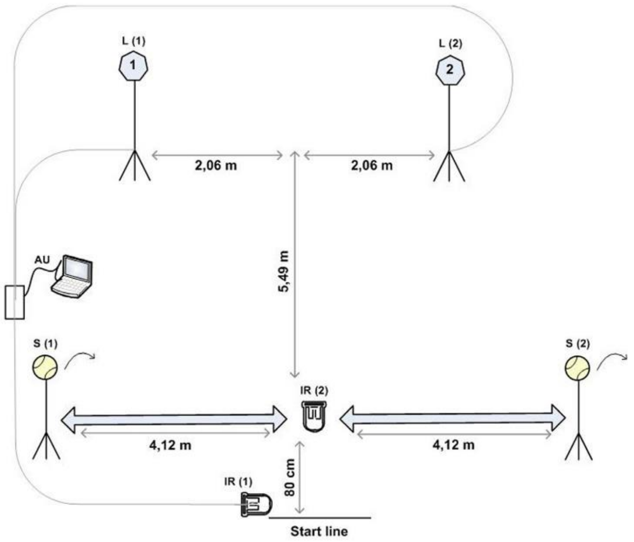


FIGURE 1
TENCODS and TENRAG test.

experimental group (EG). The biological age was calculated and determined for all participants. To participate in the study, all participants had to meet certain inclusion criteria, including being physically active players who trained for at least 6 hours a week and competed in regional, national, or international tournaments. According to the level of trainability, all participants were at least intermediate or advanced athletes. Exclusion criteria included any injury that would affect tennis play and physical performance at the start of the study. The study was conducted in accordance with the Helsinki Declaration and approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (protocol code 34; date of approval: 13 December 2021). All participants were informed of the research's purpose and the conditions for participation, and both they and their parents provided prior written consent to participate. The complete testing protocol was explained to them in detail, with a special emphasis on the additional effort required for the research and the risk of injury, which was the same level as during standard training or competition.

2.2 Measurements and procedure

The biological age of the participants was assessed through body height (cm), sitting height (cm), body mass (kg), leg length (cm), and chronological age (years). The data obtained was then entered into a specific regression equation for boys to determine PHV maturity offset: −9.236 + (0.0002708 x leg length x sitting height) + (−0.001663 x chronological age x leg length) + (0.007216 x chronological age x sitting height) + (0.02292 x ratio of body mass to body height) (Sinkovic et al., 2023). Therefore, a maturity offset of −1.0 indicates that the player was measured 1 year before peak height velocity, a maturity offset of 0 indicates that the player was measured at the time of peak height velocity, and a maturity offset of +1.0 indicates that the athlete was measured 1 year after peak height velocity. In accordance with this, age at peak high velocity (APHV) was calculated from an estimation between peak height velocity maturity offset and chronological age. The chronological age of the participants (years) was calculated by subtracting the date of birth from the date of measurement. Standing body height (cm) and sitting height (cm) were measured using a portable altimeter (Seca 213; seca gmbh, Hamburg, Germany). Leg length (cm) was calculated by subtracting the sitting height (cm) from the standing height (cm). Body mass (kg) was measured using a portable digital scale (Seca V/700; seca gmbh, Hamburg, Germany), while body fat percentage (%) was measured using the MALTRON BF 900 analyser (Maltron International Ltd., Rayleigh, United Kingdom).

The participants underwent a series of tests to evaluate their speed, agility, and explosive power. Speed assessments included 5, 10, and 20-m sprints, while agility was measured using tests such as the 20-yard run, 4 × 10-yard run, *t*-test, TENCODS, and TENRAG. Explosive power was evaluated through exercises such as the countermovement jump (CMJ), single-leg countermovement jump (CMJ_L, R), squat jump (SJ), long jump (L_JUMP), and single-leg triple jump (SLTJ_L, R). The Powertimer system

TABLE 1 Basic conditioning training program.

Training week	Exercise	Sets x reps	Pause (s)
1	Plank	3 × 30 s	30–60/90–120
	Leg raises	3 × 10	30–60/90–120
	Squat jumps	3 × 10	30–60/90–120
	Push-ups	3 × 10	30–60/90–120
2	Countermovement jump	3 × 6	30–60/90–120
	Hurdle hops forward (20–30 cm)	3 × 6	30–60/90–120
	Sprint 20 m	4 × 1	30–60/90–120
	Sprint 40 m	4 × 1	30–60/90–120
3	Plank	3 × 30 s	15–30/90
	Lunges: 3 sets x 10 reps (each leg)	3 × 10 (each leg)	15–30/90
	High knees	3 × 20 s	15–30/90
	Russian twists	3 × 10 (each side)	15–30/90
4	Squats	3 × 8	30–60/90–120
	Assisted pull ups	3 × 6	30–60/90–120
	Dumbbell bicep curls	3 × 10	30–60/90–120
	Bicycle crunches	3 × 15 (each side)	30–60/90–120
5	Agility ladder drills	3 × 10	30–60/90–120
	Shuttle runs	3 × 4	30–60/90–120
	Vertical jumps	3 × 4	30–60/90–120
	Medicine ball slams	3 × 8	30–60/90–120
6	Plank	3 × 30 s	15–30/90
	Mountain climbers	3 × 10	15–30/90
	Box jumps	3 × 4	15–30/90
	Tricep dips	3 × 8	15–30/90

(Newtest Oy, Oulu, Finland) was used to measure speed, the SportReact system (SportReact, Zagreb, Croatia) for agility, and the Optojump system (Microgate, Bolzano, Italy) for assessing explosive power during jumps. Each test was conducted three times, and the average of the three trials was then calculated for further analysis.

Before the testing session, all participants completed a standardized warm-up specific to tennis. The warm-up consisted of various activities, including light-intensity running covering a distance of 10 × 20 m. Following the running component, participants engaged in dynamic stretching exercises for a total duration of 15 min. These dynamic stretches involved lateral movements, skipping, jumping, lunges, and concluding with four repetitions of sub-maximum acceleration. Subsequently, the participants underwent tests to assess their speed (5, 10, and 20-m sprints), agility (20 yards, 4 × 10 yards, *t*-test, TENCODS, and TENRAG), and explosive power (countermovement jump, one-leg countermovement jump, squat jump, long jump, and one-leg triple jump).

2.2.1 Linear sprint speed tests

For the linear sprint speed tests, three electronic timing gates were positioned at predetermined distances of 5, 10, and 20 m from a designated starting line. Participants were instructed to their preferred foot positioning, placed on a marked line on the floor, and initiate the sprint from a stationary standing start. Their objective was to cover the 20-m distance as quickly as possible. Timing measurements were recorded at the 5-m mark (using the first electronic timing gate), the 10-m mark (using the second electronic timing gate), and the 20-m mark (using the third electronic timing gate). Each participant performed three trials, with a 3–4-min rest period between each trial. The mean value of the three trials was calculated for further analysis (Sinkovic et al., 2023).

2.2.2 Explosive power tests

During the countermovement and single-leg countermovement jump tests, participants kept their hands positioned on their hips to minimize any impact from the upper body on jump performance.

TABLE 2 Six-week plyometric training program.

Training week	Exercise	Sets x reps	Pause (s)
1	Ankle cone hops	3 × 10	15–30/90
	Ankle cone hops side to side	3 × 10	15–30/90
	Countermovement jumps	4 × 5	15–30/90
	Broad jumps	4 × 5	15–30/90
2	1-leg ankle hops forward	3 × 10	30–60/90–120
	Countermovement jumps	3 × 8	30–60/90–120
	Continious broad jumps	3 × 2 × 3	30–60/90–120
	Lateral bounds + stick	3 × 6	30–60/90–120
	2–1 Hurdle hops forward (20–30 cm)	3 × 10	30–60/90–120
3	1-leg ankle hops lateral	3 × 10	30–60/90–120
	Countermovement jump	3 × 10	30–60/90–120
	1:2 broad jumps	3 × 4	30–60/90–120
	Zig zag bounds + stick	3 × 8	30–60/90–120
	2–1 Hurdle hops lateral (20–30 cm)	3 × 10	30–60/90–120
4	1-leg square ankle hops	3 × 8	30–60/90–120
	1-leg Countermovement jump	3 × 5	30–60/90–120
	Continious broad jumps	3 × 3 × 3	30–60/90–120
	Lateral bounds (1-1-stick)	3 × 8	30–60/90–120
	2–1 Multidirectional hurdle hops	3 × 10	30–60/90–120
5	1-leg square ankle hops	3 × 12	30–60/90–120
	1-leg Countermovement jump	3 × 5	30–60/90–120
	1:2 Broad jumps	3 × 8	30–60/90–120
	Zig zag bounds (1-1-stick)	3 × 10	30–60/90–120
	2–1 Multidirectional hurdle hop	3 × 10	30–60/90–120
6	Ankle cone hops	3 × 10	15–30/90
	Ankle cone hops side to side	3 × 10	15–30/90
	Countermovement jump Broad jumps	4 × 5	15–30/90
	Broad jumps	4 × 5	15–30/90

Starting from a standing position with knees straight, participants performed a squat motion, lowering themselves to approximately a 90°, and then rapidly accelerated in a vertical direction using both legs or a single leg. Each participant completed three trials of the tests, with a 1-min rest period between each trial. The mean value of the three trials was then calculated for further analysis (Sinkovic et al., 2023).

In the squat jump test, participants started with a knee flexion angle of 90°, maintaining a straight torso, hands on hips, and feet positioned shoulder-width apart. They held this position for 2 s before initiating the jump. The push-off phase of the jump was performed without any form of countermovement. During the highest point of the jump, participants fully extended their legs. The landing phase involved both feet landing together in an upright position, with knees fully extended. Each participant completed three trials of the test, with a 1-min rest period between each trial. The mean value of the three trials was then calculated for further analysis (Sinkovic et al., 2023).

In the long jump test, participants were provided with standardized instructions to perform a long jump starting from a standing position. They were allowed to initiate the jump with bent knees and utilize arm swinging for assistance. A marked line on a hard surface served as the starting point, and the length of the jump was measured using a tape affixed to the floor. Each participant completed three trials of the test, with a 1-min rest period between each trial. The mean value of the three trials was then calculated for further analysis (Sinkovic et al., 2023).

TABLE 3 Results (Mean ± SD) of Intervention Group and Control Group Before and After the intervention Using 2 × 2 Mixed Analysis of Variance (ANOVA).

Variable	Control group		Experimental group		Interaction Time*Group			Post hoc bonferroni test	
	Initial testing	Final testing	Initial testing	Final testing					
	x̄ ±SD	x̄ ±SD	x̄ ±SD	x̄ ±SD	F	p	Partial η2	Comparison	p
Sprint 5 m (s)	1.27 ± 0.05	1.27 ± 0.09	1.27 ± 0.07	1.19 ± 0.06	7.8	0.01	0.2	CG > EG	0.01
Sprint 10 m (s)	2.12 ± 0.09	2.12 ± 0.12	2.14 ± 0.1	2.07 ± 0.1	5.76	0.02	0.15	CG > EG	0.23
Sprint 20 m (s)	3.71 ± 0.15	3.63 ± 0.24	3.79 ± 0.21	3.68 ± 0.21	0.12	0.74	0.00	-	-
CODS 4 × 10 yards (s)	10.62 ± 0.63	10.46 ± 0.49	10.64 ± 0.55	10.29 ± 0.45	1.57	0.22	0.05	-	-
CODS 20 yards (s)	5.65 ± 0.29	5.6 ± 0.28	5.62 ± 0.35	5.46 ± 0.25	2.26	0.14	0.07	-	-
CODS *t*-test (s)	12.22 ± 0.64	11.87 ± 0.63	12.14 ± 0.8	11.56 ± 0.69	3.28	0.08	0.09	-	-
Long jump (cm)	162.85 ± 16.48	165.2 ± 16.95	155.55 ± 18.18	172.8 ± 20.23	33.03	0.00	0.51	CG < EG	0.236
Triple jump_L (cm)	459.76 ± 57.44	462.93 ± 51.7	427.35 ± 65.32	461.04 ± 66.14	15.1	0.00	0.32	CG < EG	0.925
Triple jump_R (cm)	454.11 ± 56.26	451.24 ± 60.06	442.67 ± 66.39	471.14 ± 65.24	28.34	0.00	0.47	CG < EG	0.35
CMJ (cm)	23.3 ± 3.37	23.58 ± 3.34	21.56 ± 3.31	24.41 ± 3.57	28.96	0.00	0.48	CG < EG	0.48
SJ (cm)	23.1 ± 3.81	23.31 ± 3.91	21.48 ± 3.87	23.61 ± 3.86	15.9	0.00	0.33	CG < EG	0.82
CMJ_L (cm)	11.52 ± 1.57	11.73 ± 1.52	10.79 ± 1.13	12.97 ± 1.82	17.37	0.00	0.35	CG < EG	0.04
CMJ_R (cm)	11.54 ± 1.11	11.37 ± 1.37	11.21 ± 1.71	13.01 ± 2.01	22.39	0.00	0.41	CG < EG	0.01
TENCODS (s)	3.2 ± 0.17	3.18 ± 0.15	3.23 ± 0.16	3.04 ± 0.11	26.5	0.00	0.45	CG > EG	0.01
TENRAG (s)	3.38 ± 0.19	3.34 ± 0.19	3.36 ± 0.13	3.16 ± 0.17	19.08	0.00	0.37	CG > EG	0.01

Legend: CMJ (cm)—countermovement jump with arms set on hips; SJ (cm)—squat jump; CMJ_L (cm)—single leg (left) countermovement jump with arms set on hips; CMJ_R (cm)—single leg (right) countermovement jump with arms set on hips; TENCODS (s)—change of direction speed test; TENRAG (s)—reactive agility test; *—significant interaction ($p < 0.05$).

In the single-leg triple jump test, participants began by standing on one designated leg, with their toe positioned on the starting line. When ready, they performed three consecutive maximal jumps forward using the designated leg. Upper extremity movement during the single-leg horizontal hop was not restricted, although participants were instructed to land firmly on the last jump. After practice trials, three test trials were conducted on each leg in alternating order. A 30-s rest period was allowed between practice and test trials. The mean distance of the three test trials for each leg was then calculated for further analysis (Sinkovic et al., 2023).

2.2.3 Change of direction speed and reactive agility tests

In the 20-yard test, participants assumed a three-point stance and sprinted 5 yards in one direction, followed by a 10-yard sprint in the opposite direction, and then returned to the starting point. This test evaluates lateral speed and coordination. The timing commenced upon a sound of the signal and concluded when the participant crossed the timing gate upon their return. The time was measured in hundredths of a second (Sinkovic et al., 2023).

In the 4 × 10 yard test, parallel lines were marked on the floor with a distance of 10 yards between them. Participants were required to shuttle back and forth four times between the starting line and the other line as fast as possible, ensuring that both feet crossed each line during each run. The timing started upon a sound of the signal and ceased when the participant crossed the timing gate upon their return. The time was measured in hundredths of a second (Sinkovic et al., 2023).

In the *t*-test, a configuration of four cones was arranged in the shape of a "T." The starting cone was placed 9.14 m away from the first cone, and two additional cones were positioned 4.57 m from either side of the second cone. An electronic timing gate measuring 0.75 m in height and 3 m in width was set up in alignment with the marked starting point. Participants were instructed to sprint forward from the start line to the first cone (9.14 m) and touch it with their right hand. They then shuffled 4.57 m to the left to the second cone, touching it with their left hand. Next, they shuffled 9.14 m to the right to the third cone, touching it with their right hand, and then shuffled 4.57 m back to the middle cone, touching it with their left hand. Finally, they backpedaled to the start line. The timing commenced upon a sound of the signal and concluded when the participant crossed the timing gate upon their return. Trials were considered unsuccessful if participants did not touch a designated cone, crossed their legs during shuffling, or failed to face forward throughout the test. The time was measured in hundredths of a second (Sinkovic et al., 2023).

The change of direction speed (TENCODS) and reactive agility (TENRAG) variables were assessed using tests that exhibit excellent metric properties and are both reliable and valid (Sinkovic et al., 2022). The reliability of the pre-planned agility tests is slightly higher (CA = 0.92 and 0.92; ICC = 0.86 and 0.82) compared to the reactive agility tests (CA = 0.90 and 0.89; ICC = 0.74 and 0.72) (Sinkovic et al., 2022). The SportReact system (SportReact, Zagreb, Croatia)

10.3389/fphys.2023.1226831

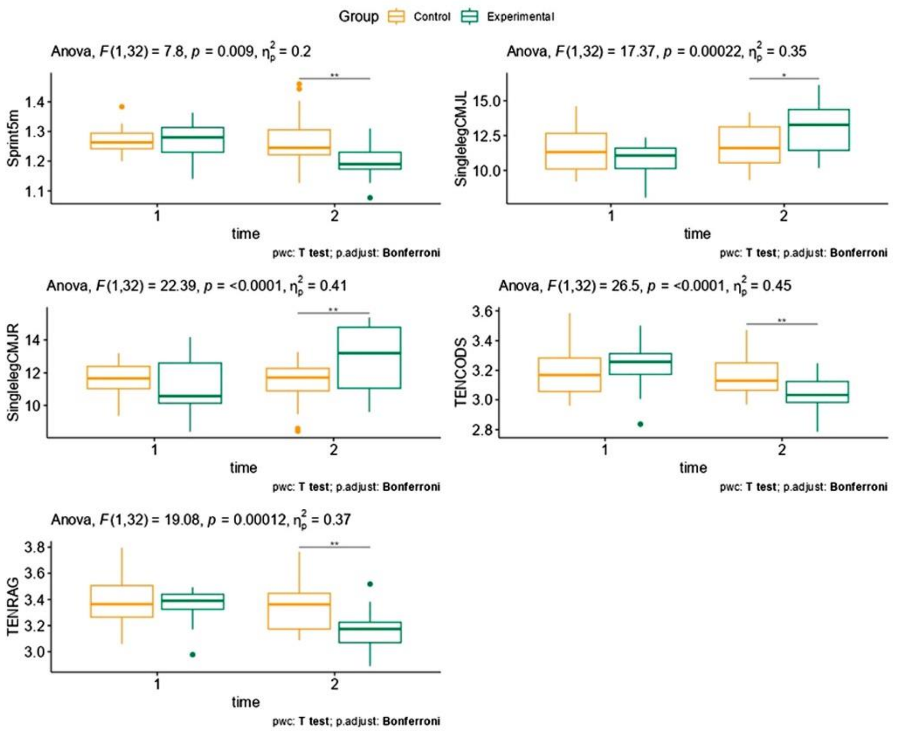


FIGURE 2
Box plots of selected variables that indicated statistically significant for 2 × 2 Mixed Analysis of Variance (ANOVA) and paired T tests.

was used to measure these tests, which consists of laser tape sensors and LED screens displaying differing signs and colors (Sinkovic et al., 2022). The TENCODS and TENRAG tests are designed to simulate specific movements in tennis (Figure 1). Participants start from a predetermined starting line, and the timing begins when the infrared signal (IR1) next to the starting line is interrupted by the "split step." At this point, one of the two lights (L1 or L2) illuminates, the participant must identify which light is lit, and perform a run with overstepping and a lateral side-to-side technique to reach a stand with a ball (S1 or S2) and hit the ball with a forehand or backhand stroke in front of their body with sufficient force for the ball to hit the ground. After playing the shot, the player should quickly return to the device in front of the starting line, interrupting the infrared signal (IR2), which stops the measurement. In the TENCODS test, participants are aware in advance of which light will illuminate, allowing them to plan their running and shot execution. Each test was performed nine times, with a 60-s break between measurement repetitions, and the mean value of the measurements was then used for further analysis (Sinkovic et al., 2022).

2.3 Study design

After the initial testing of the participants motor abilities, the control group (CG), in addition to standard technical-tactical training, continued with regular conditioning training that included a combination of strength exercises, plyometrics and agility drills. There were four standard technical-tactical training sessions and two conditioning training sessions per week. All participants were familiarized with the tests prior to the main test session. The exercises are arranged in a way that allows for a proper warm-up, progression, and targeted muscle group activation (Table 1). The experimental group (EG) underwent a 6-week plyometric training program in addition to their regular technical-tactical training sessions (Table 2). This combination ensured that both groups had an equal total load volume, the same number of training sessions, and an equal duration of training. To ensure that the participants followed the same training program, despite belonging to different clubs, licensed tennis coaches were involved in the study. The study design

TABLE 4 Heterogeneity by intervention status (n = 35).

Variable	Intervention group	Control group	Difference in variance
Sprint 5 m (s)	0.003 [0.001; 0.005]	0.009 [0.003; 0.015]	−0.006
Sprint 10 m (s)	0.004 [0.002; 0.006]	0.01 [0.004; 0.016]	−0.006
Sprint 20 m (s)	0.005 [0.001; 0.009]	0.045 [0.014; 0.076]	−0.040
CODS 4 × 10 yards (s)	0.109 [0.031; 0.187]	0.153 [0.049; 0.257]	−0.044
CODS 20 yards (s)	0.028 [0.008; 0.048]	0.047 [0.012; 0.082]	−0.019
CODS *t*-test (s)	0.131 [0.035; 0.227]	0.094 [0.023; 0.165]	0.037
Long jump (cm)	99.085 [34.236; 163.934]	37.726 [13.455; 61.997]	61.359
Triple jump_L (cm)	779.875 [212.82; 1346.93]	242.289 [87.394; 397.184]	537.586
Triple jump_R (cm)	322.594 [122.892; 522.296]	387.5 [164.476; 610.524]	−64.906
CMJ (cm)	3.825 [1.542; 6.108]	0.789 [0.266; 1.312]	3.036
SJ (cm)	3.292 [0.587; 5.997]	1.015 [0.325; 1.705]	2.277
CMJ_L (cm)	2.855 [0.985; 4.725]	0.98 [0.27; 1.69]	1.875
CMJ_R (cm)	2.316 [0.85; 3.782]	1.168 [0.37; 1.966]	1.148
TENCODS (s)	0.009 [0.003; 0.015]	0.007 [0.001; 0.013]	0.002
TENRAG (s)	0.015 [0.005; 0.025]	0.005 [0.001; 0.009]	0.010

Legend: CMJ (cm)—countermovement jump with arms set on hips; SJ (cm)—squat jump; CMJ_L (cm)—single leg (left) countermovement jump with arms set on hips; CMJ_R (cm)—single leg (right) countermovement jump with arms set on hips; TENCODS (s)—change of direction speed test; TENRAG (s)—reactive agility test.

incorporated the assistance and supervision of these coaches to ensure consistency in training implementation. To guarantee that both groups followed the same volume of training, the licensed tennis coaches closely monitored the training sessions of each group. They provided instructions and guidance to the participants, ensuring that the prescribed training volume was adhered to by both groups. The coaches maintained regular communication with the researchers to report any deviations or inconsistencies in training volume. By involving licensed tennis coaches, who were experienced and knowledgeable in training methodologies, the study aimed to minimize variations in training implementation and ensure that both groups received similar training volumes throughout the study period. Based on the expert literature, previous research and recommendations from licensed tennis coaches, the plyometric training exercises were selected for this program. The execution of the plyometric training exercises was carefully described and explained to the participants before the training sessions. Licensed tennis coaches provided detailed instructions on the technical execution of each exercise. They also used demonstrations and visual examples to show participants the correct technique. Participants were given the opportunity to practice each exercise under the supervision of the coaches to ensure proper execution of the movements and understanding of the technique. Coaches provided feedback and corrected any errors or deficiencies in exercise execution to ensure safe and effective implementation of the plyometric training. The training schedule, as shown in Table 1 and Table 2, outlined the number of weeks, exercise names, sets and repetitions, and rest periods. The participants typically performed 3 to 4 sets of 4–6 exercises, with each exercise consisting of 5–10 repetitions. They were instructed to exert maximum effort during all exercises. The rest periods between sets ranged from 15 to 60 s, while the rest periods between exercises varied from 60 to 120 s. The training sessions lasted between 30 and 45 min, including the warm-up period, and were supervised by a certified strength and conditioning coach (Novak et al., 2023). The plyometric program includes unilateral and bilateral jumps, both vertical and horizontal. The training plan was programmed based on the principle of a progressive increase in load volume, which was measured by the weekly increase in the number of jumps and the ratio between the number of bilateral and unilateral jumps per week. Each training session consisted of a preparatory, main, and final part, and there was a minimum of 48 h between two training sessions. At the end of the experiment, a final test was conducted to determine the effects of plyometric training on motor abilities, pre-planned change of direction speed, and reactive agility.

2.4 Statistical analysis

All statistical analysis was performed using R Statistical Software (version 4.2.2 R Foundation for Statistical Computing, Vienna, Austria). The normality of the distribution was tested with the Shapiro-Wilk W test. Descriptive statistics were used to determine the basic parameters of test results for each group (CG and EG) in initial and final testing phases (mean - $\bar{x}$; standard deviation—SD). Mixed model (2 × 2) ANOVA was used to determine interactions and the effect of the training program on test results. Maturity status calculated based on PHV maturity offset was included as a covariate. The partial $\eta 2$ coefficient was used as an indicator of effect size. Furthermore, when the group effect was significant, the paired *t*-test with Bonferroni correction was used for a *post hoc* analysis. For the sensitivity analysis, a complex variance model was conducted to evaluate the heterogeneity of the intervention on 15 different outcomes. It means that the constant variance assumption was loosened to allow for differential variance in outcomes to be estimated by the intervention status. This modelling offers information about the magnitude and direction of the effect on variance. Complex variance models were fitted by partitioning the level-1 variance according to the intervention status (intervention group variance (σ^2_{e1}), and control group variance (σ^2_{e2})):

$$Y_i = \beta_0 + \beta_1 Intervention_i + e_{1i} Intervention_i + e_{2i} Control_i$$

For this model, the residual distribution of the specified model:

$$\begin{bmatrix} e_{1i} \\ e_{2i} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma^2_{e1} & \\ - & \sigma^2_{e2} \end{bmatrix}\right)$$

Where Y_i represents the 15 different outcomes, $Intervention_i$ is an indicator variable for the intervention group ($Intervention_i = 1$ if one was in the intervention group) and $Control_i$ is an indicator variable for the control group. Due to the limited number of observations, the point estimation was calculated through likelihood procedures (IGLS) and then applied parametric, bias-corrected bootstraps for the fitted models, with replicate set size set to 100, max iterations per replicate set to 25, and the maximum number of sets set to 5. This procedure ran by MLwiN Version 3.05. (Centre for Multilevel Modelling, University of Bristol). The level of statistical significance was set at $p < 0.05$ and the confidence interval was 95%.

3 Results

Basic descriptive parameters of the test results were calculated and are presented in Table 3. Additionally, time*group interactions were determined for all variables. Significant interactions were observed in the sprint test results for split times at 5 m (F = 7.80; p = 0.00) and 10 m (F = 5.76; p = 0.02), indicating differences between the groups over time. However, there were no significant interactions found in the 20 m sprint test results. The best average acceleration results at 5 and 10 m were obtained in the final testing of the, EG, while the best average results at 20 m were found in the final testing of the CG. The 4 × 10 yards and 20 yards CODS tests did not show significant interactions, with the best average results achieved in the final testing of the, EG.

In tests assessing horizontal jump performance (standing long jump, triple jump_L, triple jump_R), the lowest average results were measured in the initial testing, and the best results were achieved in the final testing of the, EG. Significant interactions were also observed for these tests (p = 0.00). Regarding vertical jump performance, the triple jump_L and triple jump_R tests showed the lowest values in the initial testing and the best average values in the final testing of jump height in the, EG. Significant interactions were determined for all vertical-oriented jump tests (p = 0.00). Single leg countermovement jump (CMJ) tests yielded better results when performed with the right leg (13.01 cm).

Furthermore, the change of direction speed (TENCODS) and reactive agility (TENRAG) results also exhibited significant interactions (TENCODS - F = 26.50; p = 0.00 and TENRAG—F = 19.08; p = 0.00), with the best results being measured in the final testing of the, EG.

In addition, for all variables that were significant in 2 × 2 (time*group) an ANOVA, Bonferroni *post hoc* test (Table 3) was performed to further determine differences in each variable. The, EG showed significantly improved results in the 5 m test in the final testing compared to the initial testing, as well as in comparison to the control group in both measurements. There were no significant differences in the 10 and 20 m sprint results between the initial and final testing within the, EG. T-tests revealed no significant differences between the initial and final testing for both the CG and the, EG. Significant differences were not observed in the, EG between the initial and final testing in tests focusing on horizontal jump ability (single leg triple jump) and vertical tests performed with both legs (countermovement jump and squat jump). Furthermore, the, EG showed significant improvement (p = 0.01) in the single leg countermovement jump in the final testing. The change of direction speed and reactive agility test also exhibited significant improvement in the final testing of the, EG (p = 0.01).

The results of this research indicate that an experimental training program affected results in a set time period, i.e. 5 out of total 15 variables showed significant improvement after experimental protocol when final testing was conducted. Moreover, modelling variance by intervention status revealed that plyometric intervention indeed improved the agility, meaning that substantial heterogeneity treatment effect exists and supporting results from 2*2 mixed ANOVA. (Figure 2). displays box plots of selected variables that showed statistically significant differences in the 2 × 2 Mixed Analysis of Variance (ANOVA) and paired t-tests.

Table 4 represents the results of partitioned variance in different outcomes when assuming different variances (heterogeneity) by intervention status (level-1). When we allow complex level-1 heterogeneity by intervention status, we observed everything bar two outcome variables (CMJ and sprint 20 m), the variance of the other outcomes did not differ by the intervention status. On the one hand, the CMJ variable indicated the presence of heterogeneous treatment effect ($\sigma^2_{InterventionGroup}[\pm 1.96 * SE] = 3.825[1.542; 6.108]$, $\sigma^2_{ControlGroup}[\pm 1.96 * SE] = 0.789[0.266; 1.312]$). On the other hand, the sprint 20 m variable showed the treatment reached the control group heterogeneously rather than the intervention group ($\sigma^2_{InterventionGroup}[\pm 1.96 * SE] = 0.005[0.001; 0.009]$, $\sigma^2_{ControlGroup}[\pm 1.96 * SE] = 0.045[0.014; 0.076]$). Lastly, since the ANOVA requires the homogeneity of variances, the sensitivity analysis suggests that the main analysis sufficed one of the primary assumptions in ANOVA.

4 Discussion

The findings of this study provide strong evidence for the positive effects of a 6-week plyometric training program on motor abilities in young tennis players. The, EG demonstrated significant improvements in various aspects compared to the CG, indicating the effectiveness of the training program. Specifically, the, EG showed enhanced sprint performance at 5 m, indicating improved acceleration and speed. These improvements in sprint times highlight the positive impact of the plyometric training program on the players' explosive power and running abilities. While no significant interactions were found in the 10 and 20 m sprint test, it is important to note that the, EG still achieved better average results in the final testing phase compared to the CG. The, EG also exhibited notable advancements in jump performance. Significant interactions were observed in horizontal jump tests, with the best results being achieved in the final testing phase. This indicates that the plyometric training enhanced the players' ability to effectively generate power and explosiveness in horizontal jumps. Additionally, significant interactions were found in vertical jump tests, particularly in the triple jump tests, where the, EG showed improved jump heights in the final stage of testing. The results suggest that the plyometric exercises positively influenced the players' vertical jump performance, contributing to their overall jumping abilities. Moreover, the, EG displayed significant improvements in change of direction speed and on the reactive agility tests. These findings indicate that the plyometric training program enhanced the players' ability to change direction quickly and react to unpredictable movements, both of which are crucial in tennis. Sensitivity analysis manifested the main analysis's assumption. Hence, it was an adequate analysis. Since pre-planned change of direction speed (CODS) and reactive agility (RAG) are distinct and separate abilities influenced by multiple factors, this study represents an innovative research effort in tennis, providing valuable insights into the effects of plyometric training on both aspects. Possible reasons for a slightly greater influence on CODS comes down to the simple fact that there is no decision-making factor in these tests. The movement structure is known in advance, so the participants are less susceptible to the influence of errors during execution. While on the other hand, the RAG test is considered more complex and more difficult to perform due to the greater demand on reaction speed. It is logical that the result will be somewhat weaker. It can be concluded that RAG is influenced not only by motor abilities but also by many other cognitive factors such as observation, perception, anticipation, or decision-making speed. The plyometric training program used in this research should be employed in tennis due to its potential benefits in enhancing specific physical qualities and skills required in the sport, such as improved power and explosiveness, enhanced agility and quickness, increased speed and acceleration, enhanced lower-body strength and injury prevention. Such plyometric training program can lead to several neuromuscular adaptations that contribute to improved athletic performance. These adaptations include enhanced motor unit recruitment and synchronization, improved intermuscular coordination, increased muscle fiber activation and force production, enhanced stretch-shortening cycle utilization, and improved proprioception and reactive capabilities. These neuromuscular adaptations can result in increased power output, greater force absorption and production during explosive movements, improved movement efficiency, and enhanced overall athletic performance (Fatouros et al., 2000; Chimera et al., 2004; Markovic et al., 2007).

Plyometric training is increasingly being researched as a beneficial tool for improving motor abilities in tennis players. Several studies have examined the effects of plyometric training on tennis players and have reported positive changes in their athletic performance. In a study conducted by Sadić et al. (2011), plyometric training was found to have a positive impact on the physical fitness of young tennis players. Improvements were observed in strength, speed, and agility. Granacher et al. (2016) also investigated the effects of plyometric training in prepubescent tennis players. The results showed that plyometric training led to improvements in physical fitness, including strength, speed, and agility.

In another study by Kovacs (2006), it was found that plyometric training can enhance serve performance in pubescent boys. This study highlights the potential of plyometric training in improving specific aspects of tennis gameplay. Plyometric training has also been studied in relation to maximal power output in tennis players. Other research has focused on the effects of plyometric training on acceleration and agility in young tennis players. Čavala et al. (2017) investigated the effects of plyometric training on acceleration and agility and found positive changes in these motor abilities in young tennis players. These studies suggest that plyometric training can have a positive influence on motor abilities in tennis players. Improvements have been observed in strength, speed, agility, and specific aspects of tennis gameplay such as serving. However, it is important to note that individual responses to training may vary, and it is necessary to tailor the training program to individual needs and goals of the tennis players. Similar results have been obtained in research carried out on young soccer players (10–14 years old) where plyometric training for 6 weeks significantly improved agility results (Ramírez-Campillo et al., 2015). Other studies have reported improvements in the Illinois Agility Test scores after 7 weeks of low-volume plyometric training (Ramírez-Campillo et al., 2014). Previous studies have also shown significant changes in the Illinois Agility Test score after 8 and 12 weeks of plyometric training in prepubescent soccer players (Negra et al., 2020). Some research studies have connected the plyometric training program with the ability to change direction, reporting improvements in agility test times after 6 weeks of training (Miller et al., 2006). Similar results have been observed in handball and basketball players with an average age 22.5 ± 0.4 years, where 8 weeks of plyometric training led to decreased agility test times (Bal et al., 2011; Rameshkannan and Chittibabu, 2014). Meta-analysis studies on pubertal and young athletes have reported improvements in agility indicators by 2%–5% after the implementation of plyometric training (Markovic and Mikulic, 2010). While the present study provides evidence for the positive effects of a 6-week plyometric training program on motor abilities in young tennis players, it is important to acknowledge that there are some contradictions with previous studies. Radnor et al. (2020) conducted a systematic review and meta-analysis on neuromuscular training interventions in youth sports, including plyometric training. While they acknowledged some positive effects, they also highlighted limited evidence and inconsistent findings in regards to motor ability improvements. Similarly, Khlifa et al. (2010) investigated the effects of plyometric training with and without added load on jumping ability in basketball players. Their findings suggested that plyometric training without added load did not result in significant improvements in jumping ability compared to the control group, indicating a lack of positive effects. Furthermore, Spurrs et al. (2003) explored the impact of plyometric training on distance running performance. Their study concluded that plyometric training alone may not significantly improve distance running performance, suggesting that the effects of plyometrics may vary depending on the specific motor ability being targeted. These studies present alternative findings and indicate that the effects of plyometric training may not be universally positive for all motor abilities and sports. It highlights the need for further research to understand the specific contexts and factors that influence the effectiveness of plyometric training. Despite these contradictions, it is worth noting that the overall body of research still supports the positive effects of plyometric training on motor abilities in various sports. However, individual responses and specific contexts should be considered when implementing plyometric training programs.

Summarizing the results of previous research, plyometric training aimed at developing the ability to change direction has been conducted with different age categories for durations ranging from 6 to 12 weeks. However, agility is now classified as consisting of two branches: pre-planned change of direction speed, where the change of movement direction is known in advance, and reactive agility, which includes a cognitive component involving observation and decision-making factors (Zeljko et al., 2020). With the advancement of sports science, more studies have focused on determining the reliability of tests for assessing pre-planned change of direction speed and reactive agility. These tests are often specific, aiming to replicate situations within a chosen sport. Such research has been conducted on various athlete samples including Australian football players (Henry et al., 2013), rugby players (Green et al., 2011), netball players (Farrow et al., 2005), basketball players (Sisic et al., 2016; Sekulić et al., 2017), soccer players (Knoop et al., 2013; Gilić et al., 2019; Krolo et al., 2020), and futsal players (Benvenuti et al., 2010; Sekulić et al., 2019; Sekulić et al., 2020; Zeljko et al., 2020).

This study has certain limitations that should be considered. Firstly, the participants in this research were young tennis players in a highly sensitive and crucial stage of development. Additionally, the motor tests were conducted using a convenience sample of subjects under controlled conditions. Therefore, further longitudinal investigations are needed to thoroughly examine the impact of biological age on motor abilities in young tennis players. This research suggests that coaches and practitioners can effectively use a plyometric training program to enhance the desired physical fitness in young tennis players. Specifically, the study demonstrated that plyometric training had a greater impact on pre-planned change of direction agility rather than reactive agility, highlighting the need for including cognitive training in the development of reactive agility. Coaches should take into consideration the variations in physical performance and the practical implications of maturation when planning the long-term development of young tennis players. Future research should aim to include participants of different genders and competition categories, subsequently enabling the acquisition of more precise and comprehensive data for an enhanced practical and scientific contribution. Such information would prove valuable to coaches in designing specific conditioning strategies to foster the motor characteristics of young tennis players.

5 Conclusion

The results of this research indicated that a 6-week program dominated by plyometric training can have a significant effect on the improvement of specific motor abilities in the younger competitive categories of tennis players (U-12 and U-14). It is especially important to emphasize how the training programs impacted both abilities, namely, change of direction speed and reactive agility. However, it is important to note that there are risks and dangers associated with plyometric training, particularly for young athletes in the prepubescent and early puberty stages. This primarily pertains to moderately complex plyometric exercises that may lead to acute injuries or various overexertion syndromes. Therefore, it is crucial to adhere to methodological principles and progressively advance from simpler to more complex exercises when implementing plyometric content. Our results offer valuable insights for coaches in designing diverse tennis-specific scenarios to enhance overall performance, particularly focusing on the neuromuscular fitness of their players. Further research is required to explore interventions that can effectively improve sport-specific neuromuscular fitness, with the ultimate aim of enhancing overall performance.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Board of the Faculty of Kinesiology, University of Zagreb (Protocol Code 34; date of approval 13 December 2021). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Acknowledgments

The authors would like to thank the athletes for their willingness to participate in this investigation.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Antekolović, Lj., Žufar, G., and Hofman, E. (2003). Metodika razvoja eksplozivne snage tipa skočnosti. Zagreb. *Zagreb. sajam sporta i Naut.* 12, 219–223.

Bal, B., Kaur, P., and Singh, D. (2011). Effects of a short-term plyometric training program of agility in young basketball players. *Braz. J. Biomotricity.* 5, 271–278.

Benvenuti, C., Minganti, C., Condello, G., Capranica, L., and Tessitore, A. (2010). Agility assessment in female futsal and soccer players. *Med. Kaunas.* 46, 415–420. doi:10.3390/medicina46060058

Čanaki, M., and Birkić, Ž. (2009). Specifičnosti pliometrijskog treninga tenisača. *Hrv. Športsko-med. Vjesn.* 24, 45–50.

Čavala, M., Čoh, M., Kovač, M., and Bednarik, J. (2017). Effects of plyometric training on acceleration and agility in young tennis players. *Sport Sci. Rev.* 26, 135–148.

Chimera, N. J., Swanik, K. A., Swanik, C. B., and Straub, S. J. (2004). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *J. Athl. Train.* 39, 24–31.

Davies, G., Riemann, B. L., and Manske, R. (2015). Current concepts of plyometric exercise. *Int. J. Sports Phys. Ther.* 10, 760–786.

Farrow, D., Young, W., and Bruce, L. (2005). The development of a test of reactive agility for netball: A new methodology. *J. Sci. Med. Sport* 8, 52–60. doi:10.1016/s1440-2440(05)80024-6

Fatouros, I. G., Jamurtas, A. Z., Leontsini, D., Taxildaris, K., Aggelousis, N., Kostopoulos, N., et al. (2000). Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *J. Strength Cond. Res.* 14, 470–476. doi:10.1519/1533-4287(2000)014<0470:eopetw>2.0.co;2

Fernandez-Fernandez, J., Saez de Villarreal, E., Sanz-Rivas, D., and Moya, M. (2016). The effects of 8-week plyometric training on physical performance in young tennis players. *Pediatr. Exerc. Sci.* 28, 77–86. doi:10.1123/pes.2015-0019

Gilić, B., Uljević, O., and Tokić, A. (2019). *The influence of morphological characteristics and motor abilities on reactive and non-reactive agility in young football players*. Banja Luka: Deveta međunarodna konferencija Sportske nauke i zdravlje, 185–191.

Granacher, U., Lesinski, M., and Büsch, D. (2016). Effects of plyometric training on physical fitness in prepuberal tennis players. *J. Strength Cond. Res.* 30, 672–682.

Green, B. S., Blake, C., and Caulfield, B. M. (2011). A valid field test protocol of linear speed and agility in rugby union. *J. Strength Cond. Res.* 25, 1256–1262. doi:10.1519/JSC.0b013e3181d8598b

Henry, G. J., Dawson, B., Lay, B. S., and Young, W. B. (2013). Decision-making accuracy in reactive agility: Quantifying the cost of poor decisions. *J. Strength Cond. Res.* 27, 3190–3196. doi:10.1519/JSC.0b013e31828b8da4

Khlifa, R., Aouadi, R., Hermassi, S., Chelly, M. S., Jlid, M. C., Hbacha, H., et al. (2010). Effects of a plyometric training program with and without added load on jumping ability in basketball players. *J. Strength Cond. Res.* 24, 2955–2961. doi:10.1519/JSC.0b013e3181e37fbe

Kilit, B., and Arslan, E. (2019). Effects of high-intensity interval training vs. On-court tennis training in young tennis players. *J. Strength Cond. Res.* 33, 188–196. doi:10.1519/JSC.0000000000002766

Knoop, M., Fernandez-Fernandez, J., and Ferrauti, A. (2013). Evaluation of a specific reaction and action speed test for the soccer goalkeeper. *J. Strength Cond. Res.* 27, 2141–2148. doi:10.1519/JSC.0b013e31827942fa

Kovacs, M. S. (2006). The impact of plyometric training on tennis serve performance in pubescent boys. *J. Strength Cond. Res.* 20, 957–963.

Krolo, A., Gilic, B., Foretic, N., Pojskic, H., Hammami, R., Spasic, M., et al. (2020). Agility testing in youth football (soccer) players; evaluating reliability, validity, and correlates of newly developed testing protocols. *Int. J. Environ. Res. Public Health* 17, 294. doi:10.3390/ijerph17010294

Markovic, G., Jukic, I., Milanovic, D., and Metikos, D. (2007). Effects of sprint and plyometric training on muscle function and athletic performance. *J. Strength Cond. Res.* 21, 543–549. doi:10.1519/R-19535.1

Markovic, G., and Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Med.* 40, 859–895. doi:10.2165/11318370-000000000-00000

Milanović, L., Bašić, M., and Milanović, M. (2005). *Razvoj brzinsko-eksplozivnih svojstava u tenisu (SAQ)*. Zagreb: Informatizacija u područjima edukacije, sporta i sportske rekreacije, 328–331.

Miller, M. G., Herniman, J. J., Ricard, M. D., Cheatham, C. C., and Michael, T. J. (2006). The effects of a 6-week plyometric training program on agility. *J. Sports Sci. Med.* 5, 459–465.

Negra, Y., Chaabene, H., Stöggl, T., Hammami, M., Chelly, M. S., and Hachana, Y. (2020). Effectiveness and time-course adaptation of resistance training vs. plyometric training in prepubertal soccer players. *J. Sport Health Sci.* 9, 620–627. doi:10.1016/j.jshs.2016.07.008

Novak, D., Loncar, I., Sinkovic, F., Barbaros, P., and Milanovic, L. (2023). Effects of plyometric training with resistance bands on neuromuscular characteristics in junior tennis players. *Int. J. Environ. Res. Public Health.* 20, 1085. doi:10.3390/ijerph20021085

Radnor, J. M., Oliver, J. L., Waugh, C. M., Myer, G. D., and Lloyd, R. S. (2020). Neuromuscular training interventions in youth sport: A systematic review and meta-analysis. *Sports Med.* 50, 997–1029.

Rameshkannan, S., and Chittibabu, B. (2014). Effect of plyometric training on agility performance of male handball players. *Int. J. Phys. Educ. Fit. Sports.* 3, 72–76. doi:10.26524/14411

Ramírez-Campillo, R., Burgos, C. H., Henríquez-Olguín, C., Andrade, D. C., Martínez, C., Álvarez, C., et al. (2015). Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *J. Strength Cond. Res.* 29, 1317–1328. doi:10.1519/JSC.0000000000000762

Ramírez-Campillo, R., Meylan, C., Alvarez, C., Henríquez-Olguín, C., Martínez, C., Cañas-Jamett, R., et al. (2014). Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. *J. Strength Cond. Res.* 28, 1335–1342. doi:10.1519/JSC.0000000000000284

Sadić, I., Spasić, M., Marković, G., Kukolj, M., and Veselko, M. (2011). Effects of plyometric training on physical fitness in young tennis players. *J. Strength Cond. Res.* 25, 942–948.

Salonikidis, K., and Zafeiridis, A. (2008). The effects of plyometric, tennis-drills, and combined training on reaction, lateral and linear speed, power, and strength in novice tennis players. *J.* Strength Cond. Res. 22, 182–191. doi:10.1519/JSC.0b013e31815f57ad

Sekulić, D., Foretic, N., Gilić, B., Esco, M. R., Hammami, R., Uljević, O., et al. (2019). Importance of agility performance in professional futsal players: Reliability and applicability of newly developed testing protocols. *Int. J. Environ. Res. Public Health.* 16, 3246. doi:10.3390/ijerph16183246

Sekulić, D., Pehar, M., Krolo, A., Spasic, M., Uljevic, O., Calleja-González, J., et al. (2017). Evaluation of basketball-specific agility: Applicability of preplanned and nonplanned agility performances for differentiating playing positions and playing levels. *J. Strength Cond. Res.* 31, 2278–2288. doi:10.1519/JSC.0000000000001646

Sekulić, D., Zeljko, I., and Gilić, B. (2020). "Measuring pre-planned and non-planned agility in futsal; applicability of the newly designed sport-specific protocols," in 17th Annual Scientific Conference of Montenegrin Sports Academy, Cavtat, Dubrovnik,Croatia, 2-5 April 2020, 35.

Sinkovic, F., Foretic, N., and Novak, D. (2022). Reliability, validity and sensitivity of newly developed tennis-specific reactive agility tests. *Sustainability* 14, 13321. doi:10.3390/su142013321

Sinkovic, F., Novak, D., Foretic, N., and Zemková, E. (2023). The effects of biological age on speed-explosive properties in young tennis players. *J. Funct. Morphol.* 8, 48. doi:10.3390/jfmk8020048

Sisic, N., Jelicic, M., Pehar, M., Spasic, M., and Sekulic, D. (2016). Agility performance in high-level junior basketball players: The predictive value of anthropometrics and power qualities. *J. Sports Med. Phys. Fit.* 56, 884–893.

Spurrs, R. W., Murphy, A. J., and Watsford, M. L. (2003). The effect of plyometric training on distance running performance. *Eur. J. Appl. Physiol.* 89, 1–7. doi:10.1007/s00421-002-0741-y

Vuong, J. L., Fett, J., Ulbricht, A., and Ferrauti, A. (2022). Physical determinants, intercorrelations, and relevance of movement speed components in elite junior tennis players. *Eur. J. Sport Sci.* 22, 1805–1815. doi:10.1080/17461391.2021.2005150

Zeljko, I., Gilic, B., and Sekulic, D. (2020). Validity, reliability and correlates of futsal-specific testing protocols for agility. *Int. J. Environ. Res. Public Health.* 17, 9315.

DISCUSSION

The aim of the first study in the doctoral project was to develop and validate a new test for assessing change of direction speed and reactive agility in young tennis players. 50 tennis players (age 12.3 ± 1.2 years) took part in the study. According to the protocol for establishing the number of subjects necessary to reach statistical power, and given that tennis is an individual sport, this sample size can be considered acceptable in line with previous studies on a similar population (Eriksson et al., 2015; Huggins et al., 2017; Munivrana et al., 2022). Regarding the newly constructed tests for evaluating change of direction speed (TENCODS) and reactive agility (TENRAG), they are designed to simulate specific movements in tennis, utilizing laser tape sensors and LED screens that display various signs and colors. The assumption was that the newly constructed test would be reliable and valid, making it applicable to the sample of young tennis players. Additionally, it was assumed that the TENCODS test would have a slightly higher degree of reliability compared to the TENRAG test. This assumption was based on a literature review that indicated reactive agility is affected not only by motor abilities but also by various cognitive factors, such as perception, anticipation, and decision-making speed during the game (Henry et al., 2013; Scanlan et al., 2014; Trecroci et al., 2016).

Based on the obtained results, it can be concluded that the newly constructed tests for change of direction speed and reactive agility, according to the set thresholds, indicated moderate relative reliability but nothing more. It was assumed that the reliability was slightly higher for the TENCODS test (CA = 0.92 and 0.92; ICC = 0.86 and 0.82) than for the TENRAG test (CA = 0.90 and 0.89; ICC = 0.74 and 0.72), and this confirmed the set assumption that cognitive factors also affect reactive agility. According to the set thresholds, obtained values ranging from 0.89 to 0.92 represent an acceptable measure of the Cronbach's alpha (CA) parameter as one of the reliability indicators. However, when discussing ICC as a measure of relative reliability, some previous studies (Vincent, 2005; Weir, 2005; Weir and Vincent, 2020; Brughelli et al., 2008) categorized ICC into different levels of reliability, ranging from 'questionable' (0.7 to 0.8) to 'high' (>0.9). Also, Brughelli et al. (2008), state that most of the newly constructed change of direction tests have ICCs above 0.9 and a very low coefficient variation (CV). In accordance with such a structure, the results of the relative reliability of the constructed tests in this doctoral project (0.72 to 0.86) would be interpreted as 'questionable'. What is important to emphasize is the fact that in this study, the coefficient of variation (CV) was not calculated as a measure of absolute reliability, which is also a very important criterion for establishing the validity of the newly constructed test. The coefficient of variation (CV) is a commonly used indicator of measurement error, especially in studies with repeated tests (Bruton et al., 2000). In line with this, the CV for the newly constructed TENCDOS and TENRAG tests was calculated afterward. A review of the literature indicates that a lower CV indicates better reliability (Currell and Jeukendrup, 2008; Hopkins et al., 2001). Specifically, a CV of less than 10% has been established as the criterion for acceptable reliability (Atkinson and Nevill, 1998). Thus, the obtained results for TENCODS (CV = 4.2%) and TENRAG (CV = 4.4%) confirm that these tests exhibit acceptable absolute reliability. In comparison to other COD tests, where the majority of results typically fall within a range of 2% to 8%, the CVs for TENCODS and TENRAG are within this expected range. The inherent complexity of COD movements, along with various participant and measurement factors, contribute to the observed variability. By understanding and controlling these factors, the reliability of COD tests can be optimized, ensuring their effectiveness in assessing agility and performance.

When discussing the results of validity, it can be concluded that the newly constructed tests for change of direction speed and reactive agility have acceptable criterion validity, but according to some studies, this result is still below the required minimum. More specifically, the results of both tests show a moderate to large correlation (r = 0.60 and r = 0.55) with the agility 'T-test.' When addressing the acceptable range of validity, Impellizzeri and Marcora (2009) note in their study that benchmarks should not always be applied too rigidly, and a correlation of 0.65 instead of 0.70 cannot be interpreted as evidence against construct or criterion validity. Following this, Mejovšek (2003) recommends a moderate to large correlation range, typically between 0.60 and 0.80, for a newly constructed test. Within this range, the shared variance spans from 36% to 64%, providing sufficient grounds to assert its representation of a similar or the same construct. Such a claim must be taken with caution because, in fields like kinesiology, where shared variances can go well above 36%, it may be more appropriate to expect higher shared variances to confidently claim that constructs are identical. Also, it must be noted that in the published paper on this topic in the doctoral project, there is an overstatement in claiming that the test meets extremely good metric characteristics, as they range from moderate to large.

According to the existing literature, a solid number of agility tests with various levels of specificity have been developed and used in tennis over the years, but the majority of the used tests were primarily change of direction (CODS) tests (Barber-Westin et al., 2010; Eriksson et al., 2015; Fernandez-Fernandez et al., 2014; Huggins et al., 2017; Leone et al., 2006; Sekulic et al., 2017; Zemková and Hamar, 2014). Those tests did not really consider the cognitive aspect of agility, the "reaction to a stimulus," which would be a much better representation of the kind of agility performance needed in a real tennis match rally situation. Despite this aspect, CODS tests still play a significant role in athlete diagnostics and testing to achieve desired results. The fundamental problem is that they are based on modifying existing CODS tests by only changing the number of changes of direction and angles of movement. Additionally, for most of these tests, only relative reliability has been defined through ICC in the range of 0.70 – 0.95, while validity has not been measured. Connected to this, in this doctoral study with a similar number (n = 50), age (12.3 ± 1.2 years) and level of participants (national players), a new, sport-specific CODS test was conducted with reliable and valid results. When comparing the test developed in this dissertation with existing ones, it can be concluded that TENCDOS has significant advantages and offers something additional. Unlike most previous tests, the cones and lights are positioned exactly according to the dimensions of a tennis court. This setup ensures that the movements required in the test closely mimic those in a real match, providing a more accurate assessment of a player's agility in game-like conditions. Additionally, the test design minimizes human influence, ensuring consistency and objectivity in test administration and results. The sample of participants in this dissertation, unlike previous studies, targets the early puberty and puberty phases. This is crucial for the development of the motor skills being assessed, as these stages of growth are key periods for enhancing agility. Furthermore, such a sample is often underrepresented in existing research, making this dissertation and test particularly valuable. Also, unlike some complicated tests, this one is simple to administer, with a very clear structure, and does not require much time to set up. This makes it highly practical for coaches and practitioners, allowing for efficient use of time and resources while maintaining accuracy and reliability in assessing agility.

In terms of newly constructed RAG tests in tennis, a comprehensive systematic literature search yielded that there are only a few tennis-specific tests, including a response to a stimulus, showing reliable and valid results (Ulbricht et al., 2016; Jansen et al., 2021b; Munivrana et al., 2022; Wisnu-Nugroho et al., 2022). When comparing the obtained results of this doctoral dissertation with the findings of previous research on the construction of new tests for assessing reactive agility in tennis, similar results can be observed. It should be noted that one of the tests used in the study of Ulbricht et al. (2016) included both physical and cognitive aspects of agility, but some of the parameters used in the test made it more of a tennis-specific sprint speed test than a real reactive agility test, and the test has no reliable and valid outcomes. Furthermore, in the study by Wisnu-Nugroho et al. (2022), the gender, age, and level of participants were not reported. The results of the mentioned study showed an ICC test value of 0.50, indicating a low level of reliability. When compared to the results of this doctoral dissertation, the test demonstrated weaker performance in relation to the newly constructed TENCODS and TENRAG tests. The other tests (TAT and TS-RAN) are currently the two best newly constructed tests for assessing RAG ability. Both tests have shown similar results in terms of reliability and validity, but it is important to note that there are also differences between them. These differences are evident in the number of participants, age, level, and method of implementation. For instance, in the TAT test, the sample of participants was very young (10 years), while the TS-RAN included older participants (>20 years). Comparing the age of participants with this doctoral dissertation, it can be observed that the participant sample in the dissertation included early puberty and puberty phases, which is innovative and differs from previous studies. Despite these differences, both tests (TAT and TS-RAN) were constructed in a Y-shape format with a reaction to stimulus (lights), and similar to this doctoral dissertation, the ICC was > 0.70 and CV < 10%. Such results can be considered acceptable, but with the aim of improving the test characteristics to achieve an even higher interclass correlation coefficient to make them even more practically applicable. Also, it is important to note that previous studies, including this doctoral dissertation, for validating the newly constructed RAG test, did not compare it to another RAG test but rather to a CODS test, which can be considered a limitation. Additionally, the newly constructed TENRAG test in this doctoral dissertation has clearly defined cone and light positions and does not include imitation of a shot or human factor, unlike previous research that encompasses these shortcomings.

In conclusion, the newly constructed test for change of direction speed and reactive agility was found to be reliable and valid, but according to some previous studies with more rigorous thresholds, the obtained results may be questionable, which could impact their practicality. This is likely due to a short test duration (< 3 sec) with a limited number of changes of direction – only one. In line with that, when designing COD tests, it is crucial to adhere to specific time frames that are physiologically defined. Tests should ideally last around 5 seconds to ensure they target the precise physiological responses related to COD ability. Within this timeframe, tests can stimulate the rapid acceleration, deceleration, and re-acceleration patterns characteristic of sports movements requiring agility. This approach ensures that the test accurately measures COD ability without compromising the specificity of the physiological demands. Therefore, the aims of future research could involve constructing a similar test with a longer duration (~5 sec) and a higher number of changes of direction (> 3) to achieve higher reliability and validity results. Considering all of the above, it can be concluded that such a test can be used in practice, but its effectiveness may be limited. According to its metric characteristics, interpretations of results should be made with caution. What favors these tests is that through a review of the literature, it has not been established that there are many better specific tests and opportunities for developing reactive agility in tennis. Such field-based tests better describe the player's motor performance efficiency related to technical execution compared to basic tests. Also, the mentioned tests provide more detailed information about the actual state of those traits and abilities that ultimately ensure a player's success at the elite competitive level.

Connected to the first study, one of the questions to be addressed in the doctoral project is whether there is a correlation between the results in basic tests of different motor abilities and the newly constructed tests of specific change of direction speed and reactive agility. This question is crucial for several reasons. Firstly, understanding the relationship between fundamental motor skills such as speed, power, and sports-specific agility can provide insights into how foundational physical abilities contribute to higher-level athletic performance. Secondly, it can aid in optimizing training programs by focusing on developing those foundational skills that are most closely associated with success in agility-based tasks. Moreover, identifying strong correlations can help coaches recognize athletes with the potential for high performance in sports requiring quick changes of direction and reactive movements. Furthermore, in terms of correlations between speed, agility, and power, it is evident that the results vary across different types of basic change of direction speed (CODS) tests, and none of these correlations were examined with newly constructed CODS tests. However, an even more significant problem arises with the correlation between speed, agility, and power with reactive agility (RAG) tests, where none of the reported studies have explored the correlation between anthropometric characteristics and motor abilities with RAG tests. Additionally, investigating these relationships can contribute to the development of more comprehensive athlete assessment protocols and targeted training strategies aimed at enhancing reactive agility, which is increasingly recognized as one of the most important abilities in competitive sports. Therefore, addressing these correlations in the context of both CODS and RAG tests is essential for advancing the understanding of athletic performance and optimizing training methodologies. Accordingly, the published paper had the aim of investigating the correlation between speed, agility and explosive power in young tennis players. The sample was the same as in the previous study, consisting of 50 tennis players (age 12.3 ± 1.2 years) who held rankings within the top 50 positions of the National Tennis Association and also within the top 300 on the international "Tennis Europe" rankings. The assumption was that there is a significant correlation between anthropometric variables and motor abilities with change of direction speed and reactive agility performance. Such insights could provide useful information for coaches in creating a wide range of tennis-specific exercises to enhance performance, especially in a player's neuromuscular fitness.

The analysis of the results reveals two important findings. Firstly, young tennis players achieve better results in the change of direction speed test (3.20 ± 0.16 seconds) compared to the reactive agility test (3.36 ± 0.16 seconds). The better performance in change of direction speed test can be attributed to the absence of decision-making factors and the known movement structure in advance, making participants less susceptible to errors during execution. On the other hand, the reactive agility test is considered more complex and challenging due to the greater demand on reaction speed, logically resulting in a potentially lower performance (Henry et al., 2013; Scanlan et al., 2014). Secondly, there is a statistically significant correlation of TENCODS and TENRAG with anthropometric characteristics (body height and body mass), running speed tests (5, 10, and 20 m sprints), change of direction speed tests (20 yards, 4x10 yards, T–TEST) and horizontal explosive power variables (standing long jump, and single-leg triple jump), while there is no statistically significant correlation with vertical explosive power variables (countermovement jump, single-leg countermovement jump and squat jump). However, based on the obtained results, it can be seen that the correlations marked as significant are not extremely large, ranging within 0.30 – 0.63, indicating a moderate correlation. More specifically, the largest correlation (r = 0.47 to 0.61) was obtained between change of direction speed tests (20 yards, 4x10 yards, T–TEST), which is logical since they are constructed in a similar way to TENCODS and TENRAG, containing similar movement patterns. The correlations varied across different COD tests due to potential slight differences in their specific testing protocols, such as the distance covered, number of directional changes, and rest intervals. Additionally, tests may differ in duration and the complexity of movement sequences. Therefore, these differences in movement demands can lead to variations in the observed correlations. Furthermore, the T-TEST shows the greatest correlation with the newly constructed TENCODS and TENRAG tests primarily because they share similar movement patterns, which involve rapid changes in direction, acceleration, and deceleration over short distances. Specifically, the T-TEST includes forward, lateral, and backward movements around cones, which are similar to the movement patterns and demands found in TENCODS and TENRAG tests. Also, the 20 m sprint time (r = 0.51) falls within the range of the highest correlation. Such a result can be attributed to the fact that both assessments require athletes to quickly accelerate from a stationary position, which is a critical component contributing to their high correlation. Despite the 20 m sprint being a linear test and TENCODS and TENRAG involving directional changes, the initial burst of speed and ability to generate high velocity over a short distance are crucial in both contexts. This correlation highlights the importance of foundational athletic attributes such as lower-body power, muscular strength, and fast-twitch muscle fiber dominance, which are essential for performing well in both sprinting and agility tasks. Furthermore, it is important to note that the correlation between TENCODS and TENRAG tests was not presented in the published manuscripts but was calculated subsequently (r = 0.79). According to the established thresholds, such a correlation can be considered large. These results indicate that the correlation between TENCODS and TENRAG is greater than any correlation observed between other COD tests and TENCODS. Specifically, TENCODS exhibits a higher correlation with TENRAG than with the T-TEST, for instance, which is considered the "gold standard" COD test. Several factors can contribute to such results. First and most importantly, TENCODS and TENRAG are essentially identical tests with the same construction, including the same number of directional changes, duration, cone placements, and light configuration. Therefore, it is logical that their correlation would be high. The only difference between these two tests lies in TENRAG's inclusion of reactions to stimuli, whereas TENCODS involves pre-defined movements. Accordingly, these results suggest that TENCODS may be more similar to TENRAG than to other COD tests, which could indicate somewhat lower and questionable validity.

Given that the mentioned newly constructed tests are supposed to measure different abilities, it is also important to establish the correlation between these two tests separately. Thus, the TENCDOS test shows a statistically significant moderate correlation with body height and body mass (r = -0.30) but not with other anthropometric characteristics (body fat and body mass index) (r = -0.08 to -0.22). When it comes to correlations with speed (5, 10, and 20 m sprints) and CODS (20 yards, 4x10 yards, T–TEST) abilities, moderate correlations were found with all measured tests (r = 0.40 to 0.56). The biggest differences in correlations were found in tests of explosive power, where moderate correlations (r = -0.37 to -0.49) were found between TENCODS and all measured horizontal jump tests (standing long jump and single-leg triple jump), while correlations with vertical jump tests (countermovement jump, single-leg countermovement jump, and squat jump) are small and not statistically significant (r = -0.14 to -0.27). When comparing these results with previous research, it can be concluded that similar findings were established. For instance, in a sample of young male tennis players (aged 13-15 years), low to moderate correlations were found between CODS tests (Fan drill and Spider drill) and anthropometric characteristics (Filipčić and Filipčić, 2005; Kumar, 2017). Furthermore, concerning the relationship between CODS tests (Fan drill, Tennis drill, Hexagon test, T-test) and sprint speed (5m, 10m, and 20m) in young junior tennis players competing at the national level, moderate correlations were found in almost all previous studies (Filipčić and Filipčić, 2005; Leone et al., 2006; Hernandez-Davo et al., 2021). Slightly higher correlations were found with results in longer distances (20m sprint) compared to shorter ones (5m sprint), as confirmed in this dissertation. Furthermore, regarding explosive power, Munivrana et al. (2015), in a sample of 154 male tennis players aged 15-18 years, also did not establish a significant correlation (r = 0.03 to 0.12) between CODS tests (Fan drill, 9×6m test) and results in the vertical jump test. In contrast, some authors (Filipčić and Filipčić, 2005; Pauole et al., 2015; Hernandez-Davo et al., 2021) in samples of young, college-age participants with undefined tennis experience, found moderate correlations between CODS tests and both vertical and horizontal tests of explosive power. In summary, according to the results of this dissertation and previous studies, it can be discussed how body height and body mass are correlated with performance in the COD test due to the specific demands of the test. Conversely, the lack of significant correlation with body fat and BMI indicates that these specific measures of body composition do not significantly impact performance in the test. One of the reasons for these findings may be the fact that the COD test measures dynamic physical abilities that rely more on muscular power, coordination, and agility than on body composition metrics alone. Furthermore, speed and COD tests demand rapid acceleration and deceleration, as well as efficient changes in direction. These movements rely heavily on fast-twitch muscle fibers, which provide the explosive power needed for quick bursts of speed and agility. Additionally, neuromuscular coordination is essential in both types of tests, as it allows for precise and rapid muscle contractions and adjustments during high-speed and agile movements. This shared reliance on these properties can explain the existing and consistent correlations observed between speed and COD tests. The moderate correlations between the TENCODS test and horizontal jump tests, suggest that horizontal power plays a significant role in CODS performance. Horizontal jumps require strong explosive power and the ability to generate force in a horizontal plane, which directly translates to rapid acceleration and effective changes in direction. In contrast, the small and statistically insignificant correlations with vertical jump tests indicate that vertical power may not be as crucial for CODS performance in this context. This discrepancy could be due to the different mechanics involved in vertical versus horizontal jumps. Vertical jumps primarily measure the ability to generate force vertically, which might not align as closely with the lateral and forward movements required in CODS tests. However, some previous studies also found moderate correlations between CODS tests and both vertical and horizontal tests. This divergence in findings could be attributed to several factors. Firstly, the differences in the population samples, such as age, training background, and specific athletic skills, might influence the relationship between CODS and vertical power. Athletes with varied training experiences and skill levels might exhibit different physical adaptations, affecting their performance across different types of power tests. Secondly, the methodology and specific tests used in different studies might contribute to these discrepancies. Variations in test protocols, measurement techniques, and the specific demands of the CODS tests could impact the observed correlations. In conclusion, while horizontal power consistently correlates with CODS due to its direct application in lateral and forward movements, the role of vertical power may vary depending on the athlete's background and the specific demands of their training regimen.

When it comes to correlations between the TENRAG test and anthropometric variables and motor abilities, the results are similar to those of the TENCODS test, suggesting that these tests actually capture similar qualities. Thus, the TENRAG test shows a statistically significant moderate correlation with body height, body mass, and body mass index (r = -0.30 to -0.41) but not with body fat (r = -0.18). When it comes to correlations with speed (5, 10, and 20 m sprints) and CODS (20 yards, 4x10 yards, T–TEST) abilities, moderate correlations were found with all measured tests (r = 0.33 to 0.61). In tests of explosive power, moderate correlations (r = -0.40 to -0.48) were found between TENRAG and horizontal single-leg triple jump test, but not in the horizontal standing long jump test (r = -0.21) as is the case with correlations with the TENCODS test. When it comes to the relationship with vertical jump tests (countermovement jump, single-leg countermovement jump, and squat jump), all obtained correlations are small and not statistically significant (r = -0.03 to -0.14). When comparing the mentioned results with previous research, it can be concluded that similar findings were established. However, what can be immediately noticed is that there is a very limited and low number of studies considering the correlation between speed, agility, and explosive power with RAG tests in tennis. Jansen et al. (2021b), in their research on a sample of 69 junior players with unreported gender, identified a positive moderate correlation (r = 0.70) between the Spider drill CODS test and the Tennis-Specific Agility Test. Similarly, Munivrana et al. (2022) found a positive moderate correlation (r = 0.79) between the Side-Step CODS test (STSLA) and the newly constructed Tennis-specific Reactive Agility Test (TS-RAN) among 32 youth tennis players (21 males and 11 females; 10.8 ± 1.5 years). As already mentioned, these findings are in line with the results of this dissertation where moderate correlations were found between the TENRAG test and both basic CODS and the newly constructed TENCODS test. Moreover, none of the mentioned studies presented the correlation between anthropometric characteristics, speed and power with RAG tests. Instead, only comparisons between existing CODS and newly constructed RAG tests were made. By investigating how factors like body composition, sprinting abilities, and explosive power correlate with RAG performance, researchers can provide a more comprehensive assessment of an athlete's agility profile. This knowledge informs tailored training programs aimed at enhancing specific attributes that contribute most significantly to agility. Furthermore, understanding these correlations supports evidence-based training and conditioning strategies, ensuring that athletes develop the necessary physical qualities to excel in agility-demanding sports.

In line with all the mentioned aspects, when comparing the tests, it is evident that there are similarities between the correlations of different motor abilities in the TENCOD and TENRAG tests. Specifically, only two variables (body mass index and the standing long jump test) show different correlation results between these two tests. Regarding differences, TENCODS doesn't correlate significantly with body mass index, while TENRAG shows a moderate correlation. This suggests that body mass index might have a slightly greater impact on performance in TENRAG compared to TENCODS. This could be due to the specific physical demands and nature of each test. TENRAG, focusing on rapid agility and reaction time, may place different biomechanical and physiological stresses on athletes compared to TENCODS. The standing long jump is the only difference between these new tests concerning motor abilities and explosive power, with a slightly greater impact on CODS performance. Therefore, the standing long jump's greater impact on CODS performance compared to RAG can be attributed to its direct assessment of horizontal explosive power, which aligns closely with the initial burst and acceleration demands of CODS tasks. In contrast, while agility and reaction time are crucial in RAG tests, they involve a broader range of movement skills and may not place as much emphasis on the specific type of explosive power needed for rapid directional changes seen in CODS scenarios. In conclusion, it can be stated that this doctoral study confirmed the assumption that there is a significant correlation between anthropometric variables and almost all motor abilities with change of direction speed and reactive agility performance. However, the obtained results indicate that the correlations are not extremely large, as stated in the published studies. Such results open the door for further in-depth investigations on similar topics, offering the potential for new insights and advancements in this field, particularly among young tennis players during both the early puberty and puberty phases.

Based on the fact that plyometric training holds the potential and provides a training advantage for improving sports performance in various athletic populations (Markovic and Mikulic, 2010), the aim of the third study in this doctoral dissertation is to determine the effect of 6 weeks of plyometric training program on speed, explosive power, change of direction speed, and reactive agility in young tennis players. The participants in this study included 35 male tennis players (age 12.14 ± 1.3 years, height 157.35 ± 9.53 cm, and body mass 45.84 ± 8.43 kg at the beginning of the experiment). Eighteen of the participants were randomly assigned to the control group, and seventeen were assigned to the experimental group. The frequency of training was 2 times per week, and the training sessions lasted between 30 and 45 minutes. The participants typically performed 3 to 4 sets of 4–6 exercises, with each exercise consisting of 5–10 repetitions. Reviewing the existing literature, it can be concluded that the data are comparable to previous studies on a similar topic. Thus, a total of 17 studies on a similar topic were found, with the number of participants ranging from 16 to 64 and the age ranging from 11 to 25 years, with most having more than 2 years of tennis experience and being at the national level. Accordingly, it can be considered that the population characteristics of this study are acceptable. As for the characteristics of the programs, in most of the studies, the number of training sessions ranged from 2 to 3 times per week. The duration varied from 20 to 60 minutes, while the entire plyometric training programs lasted from 6 to 8 weeks in almost all studies. When it comes to measured tests of motor abilities, running speed (sprints at 5, 10, and 20 m), change of direction speed (4 × 10, 20 yards, T-TEST, TENCODS), reactive agility (TENRAG), and explosive power (long jump, single-leg triple jump, countermovement jump, squat jump, and single-leg countermovement jump) were tested.

The findings of this study provide evidence for the positive effects of a 6-week plyometric training program on some motor abilities in young tennis players, particularly when considering its impact on CODS and RAG abilities which contributes to the novelty in this field of research. The experimental group (EG) demonstrated significant improvements in various aspects compared to the control group (CG), indicating the effectiveness of the training program. Specifically, the EG showed enhanced sprint performance at 5m and 10m, indicating improved acceleration and speed. These improvements in sprint times highlight the positive impact of the plyometric training program on the players' explosive power and running abilities. In contrast, no significant interactions were found in the 20 m sprint test. The EG also exhibited notable advancements in jump performance. Significant interactions were observed in horizontal jump tests, with the best results being achieved in the final testing phase. This indicates that the plyometric training enhanced the players' ability to effectively generate power and explosiveness in horizontal jumps. Additionally, significant interactions were also found in vertical jump tests, where the EG showed improved jump heights in the final stage of testing. The results suggest that the plyometric exercises positively influenced the players' vertical jump performance, contributing to their overall jumping abilities. Moreover, the EG displayed non-significant improvements in change of direction speed tests (4 × 10, 20 yards, T-TEST), but statistically significant improvements were obtained in the newly constructed TENCODS and TENRAG tests. Specifically, 5 out of total 15 variables showed significant improvement after experimental protocol when final testing was conducted. The experimental group showed significantly improved results in the 5m sprint test (6.3%) in the final testing phase compared to the initial testing phase, this was also the case in comparison to the control group in both measurements. Furthermore, the experimental group showed significant improvement in the single leg countermovement jump (16.1% and 20.2%) in the final test, as well as in comparison to the control group in both measurements. The change of direction speed and reactive agility test also exhibited significant improvement (5.9% and 6.0%) in the final testing phase of the experimental group.

When it comes to the effect of plyometric training on speed abilities, the results of this dissertation showed a significant impact of the designed plyometric training program on short sprint speed (5m and 10m). Such findings were expected since the program consisted of a large number and frequency of foot contacts with the ground, thus expecting the development of explosiveness and starting speed. Furthermore, the results of this dissertation are similar to previous research. For instance, Salonikidis and Zafeiridis (2008) found a significant improvement in the 4m and 12m side and forward sprint for both the combined group (plyometric training + tennis drills) and the plyometric training group alone. It is notable that the sample consisted of amateur (novice) level players, and it would certainly be interesting to conduct such research with more experienced tennis players (over >3 years of training). Also, the age of participants (21.1 ± 1.3 years) suggests that the results might vary if conducted during the prepuberty and puberty phases. One of the studies involving elite players with over 8 years of training experience was conducted by Fernandez-Fernandez et al. (2015), where they found that explosive strength and repeated sprint training over 8 weeks significantly improved results (0.56% - 1.12%) in the 10m sprint test and the repeated sprint test. However, no difference was observed in longer sprint distances (20m and 30m). In line with that, with a sample of participants similar to this dissertation (16.9 ± 0.5 years), it was also confirmed that plyometric training has a greater impact on shorter sprint distances compared to longer ones. Additionally, it must be noted that in this research, the plyometric training program consisted not only of jumping exercises but also of general explosive strength and repeated sprint exercises. Furthermore, Fernandez-Fernandez et al. (2016) found, with a younger (13 years old) and less experienced sample, that a plyometric training program over 8 weeks could significantly improve results in shorter sprint distances (5m and 10m) but also in some longer distances (20m) by 3-10%. A positive impact of plyometric training on sprint distance (5m, 10m, 20m, 50m) was also found in other studies (Fernandez-Fernandez et al., 2018; Mohanta et al., 2019; Fernandez-Fernandez et al., 2020; Kanabar et al., 2022; Gamlath and Thotawaththa, 2023). In all mentioned studies, a similar sample was used, with tennis experience of at least 2 years, and the plyometric training program included 2-3 sessions per week for 6-8 weeks. But one of the rare studies with contrasting results was conducted by Novak et al. (2023), where they reported that a plyometric training program with a frequency of 2 times per week and a duration of 6 weeks did not significantly affect sprint tests at 5m, 10m, and 20m in tennis players aged 12-14 years. What is specific about this study and may have contributed to such results is the fact that the plyometric training program was not conducted in the traditional manner but rather with the use of resistance bands. The assumption is that a plyometric training program in this research, without the use of resistance bands, would show more similar results to previous studies, as well as to this doctoral dissertation. Summarizing these comparisons, it is evident that plyometric training primarily focuses on enhancing the stretch-shortening cycle of muscles, which is crucial for explosive movements over shorter distances. The quick bursts of power required for accelerations over 5m and 10m align closely with the benefits provided by plyometric exercises such as different jumps. These exercises improve muscle elasticity and neuromuscular coordination, enhancing the athlete's ability to generate force rapidly. Conversely, the 20m sprint involves sustaining speed over a longer distance, which demands not only initial acceleration but also the maintenance of velocity. Plyometric training may be less effective in improving endurance-related aspects of sprinting beyond the initial acceleration phase. Endurance qualities like aerobic capacity and muscle fatigue resistance play a more significant role in longer sprints, which are not directly targeted by plyometric exercises.

When it comes to the effect of plyometric training on explosive power abilities, the results of this dissertation showed a significant impact of the designed plyometric training program on all measured jumping tests. Such findings were expected and logical since the program is mostly based on jumping exercises with different frequencies and repetitions, including both horizontal and vertical directions. Accordingly, the results are in line with other studies on similar topics. Specifically, in almost all presented studies, positive impacts of neuromuscular and plyometric training on explosive power were shown. For example, Fernandez-Fernandez et al. (2015), with a sample of elite tennis players with over 8 years of tennis experience, found a statistically significant impact of explosive strength and repeated sprint training on the countermovement jump (CMJ) after 8 weeks of implementation, with improvements ranging from 0.56% to 1.12%. The mentioned training program includes not only jumping exercises but also explosive strength and repeated sprint exercises, and the percentage of impact on the countermovement jump would likely be even greater if only plyometric exercises were performed. Such claims were found by Fernandez-Fernandez et al. (2016) and Fernandez-Fernandez et al. (2020) on younger and less experienced tennis players, with improvements in countermovement jump ranging from 3% to 10% after 8 weeks of plyometric training. As assumed in the previously mentioned study, the percentage of change is somewhat higher since the training program predominantly consisted only of jumping exercises. Additionally, Novak et al. (2023), in their study, demonstrated a positive impact of plyometric exercises with resistance bands, conducted with a frequency of 2 times per week, lasting 30-45 minutes each session, over a duration of 6 weeks on the countermovement jump. It is also worth noting that the program used in this research is very similar to the program in this doctoral dissertation. Furthermore, Mohanta et al. (2019) compared the difference between experimental plyometric training and circuit training and found significant improvements in vertical jumps of more than 22% in both programs. The biggest difference between the mentioned study and the dissertation lies in the sample characteristic, as it involves slightly older participants aged 18-25 years. When discussing the effect of plyometric training on horizontal jumps, Barber-Westin et al. (2015) and Fernandez-Fernandez et al. (2016), on a sample of male and female tennis players of similar age (12-14 years), indicated that plyometric training, conducted 2-3 times a week for 8 weeks, led to improvements in tests such as the single-leg long jump and standing long jump (up to 10%). Such results were also confirmed by Kanabar et al. (2017) in their study involving 40 male and female junior tennis players, where they found that both plyometric training and agility ladder training significantly positively influenced the performance in the standing long jump. Such claims are in line with the obtained results of this dissertation, where a positive impact of plyometric training on both vertical and horizontal jumps was observed. In contrast, only Novak et al. (2023) established that there is no improvement in horizontal jump tests when it comes to the impact of plyometric training among participants aged 12-14 years at the national level of play. However, since the exercises of plyometric training in this study were provided with resistance bands, that can be a possible contributing factor to the contradictory results. The only limitation that can be noted is that most previous studies have included a very limited number of tests, typically consisting of the countermovement jump test, vertical jump, and standing long jump tests. In contrast, this doctoral dissertation incorporates a greater variety of tests for assessing vertical and horizontal power, such as the triple jump test, squat jump test, and one-leg countermovement jump test. The inclusion of these additional tests expands the scope to evaluate various aspects of power generation and neuromuscular coordination. However, it is possible that the results of these additional tests may sometimes be similar to the traditional tests, thus questioning their necessity. Nonetheless, they will contribute to a more comprehensive understanding of an athlete's performance profile. Moreover, comparing the results of this dissertation with previous studies allows for a discussion on how the findings indicate a significant impact of the designed plyometric training program on all measured vertical and horizontal jumping tests. These conclusions stem from the fact that plyometric training is well-known for its ability to enhance explosive power, which is essential for optimal jumping performance. This training method facilitates rapid muscle contractions, heightens muscle fiber activation, and enhances movement coordination, collectively leading to more effective force generation during jumps. Regular engagement in plyometric exercises enables muscles to better generate force over shorter durations, thereby improving both jump height and distance. These findings substantiate that a structured plyometric program effectively develops explosive capabilities, offering empirical evidence to support the integration of such methods into athletic training programs aimed at maximizing jumping performance.

One of the most important parts of this doctoral dissertation is to discuss the obtained results related to the effect of a plyometric training program on change of direction speed and agility performance. Given that the mentioned CODS tests are foundational, well-established, and validated, whereas TENCODS and TENRAG are new tests with questionable validity, claims in the published study within the dissertation asserting that plyometric training significantly affects CODS and RAG should be approached with caution. The increased complexity of these new tests may have provided a more sensitive measure of agility performance, thereby detecting greater improvements following plyometric training. Additionally, the plyometric training program in this dissertation includes exercises such as lateral bounds, multi-directional jumps, and agility ladder drills, which can enhance agility performance by improving neuromuscular coordination, muscle power, and reactive ability. Another reason may be found in the sample of participants, where participants may have been less familiar with the TENCODS and TENRAG tests compared to traditional CODS tests, leading to greater potential for improvement. Familiarity with a test can influence performance due to factors such as anticipation and motor learning. In line with that, the novelty of the TENCODS and TENRAG tests may have allowed participants to demonstrate greater gains in agility following plyometric training. Additionally, individual differences in training responsiveness, movement mechanics, and baseline agility levels can influence the magnitude of improvements observed following plyometric training. Some participants may naturally perform better in certain agility tests while others show slower progress. Analyzing individual responses within the experimental group can provide valuable insights into the factors influencing reactive agility improvements following plyometric training. However, it must be noted that due to the differences in the impact between the CODS and TENCODS tests, both of which have similar patterns of movement, TENCODS could have a low and questionable level of validity, as explained and discussed in the first section of the doctoral dissertation. Before comparing the results of this study with previous research, it's important to note that this doctoral dissertation makes a significant scientific contribution to this topic because there is a very limited amount of research on the effect of plyometric training on newly constructed CODS and RAG tests. While some studies have shown the effect of this type of training on existing and basic CODS tests, only one study presents the effect of a plyometric training program on a RAG performance (WS-S test) (Novak et al., 2023). In line with that, Fernandez-Fernandez et al. (2016) conducted a study with a sample of 60 male participants at an international level of play and established statistically significant improvements (up to 10%) in the CODS 5-0-5 test after an 8-week plyometric training program. Since the aforementioned study found a significant effect of plyometric training on the CODS test, the results contrast with those of the dissertation, where only newly constructed tests with questionable validity showed improved effects. One possible reason is the length of the plyometric program, as it lasted 8 weeks while in the dissertation it was only 6. Therefore, it can be concluded that a longer duration of the program could affect the significance of the results. Continuing from the previous study, Fernandez-Fernandez et al. (2016) conducted research on a similar sample of participants in terms of age (13 years), but with slightly higher tennis experience and level of play. They found that neuromuscular training before tennis-specific training significantly influenced the improvement in the performance of the CODS 5-0-5 test, while neuromuscular training after tennis-specific training did not show a significant impact on the same test. These results are interesting because they demonstrate a difference in the timing of the training program implementation, and the results of the plyometric program in this dissertation could also yield different results if compared in terms of before and after tennis-specific training. Compared to the results in the dissertation, Fernandez-Fernandez et al. (2020) and Novak et al. (2023) also established that plyometric training does not have a statistically significant impact on the CODS 5-0-5 test and CODS T-test after conducting plyometric training programs with resistance bands, but with a slightly shorter duration of 6 weeks. As already mentioned, it is possible that the plyometric program would yield different and more significant results if the length were longer (8-9 weeks). When it comes to older participants (18-25 years) with no reported tennis experience and a lower level of play (amateur, college, and regional), it was found that an 8-week plyometric program with sessions lasting 30-60 minutes per session significantly improves results in the CODS T-test (>13%), Illinois test, Hexagon test, and Spider drill test (Rathore, 2016; Lakshmikanth et al., 2018; Ziagkas et al., 2019; Mohanta et al., 2019; Gamlath and Thotawaththa, 2023). It can be concluded that the greatest impact was obtained with slightly older participants who are more experienced and have a higher level of play. Regarding the effect of plyometric training on sport-specific newly constructed CODS and RAG tests, there are very limited studies on this topic. Barber-Westin (2015) examined a study with a sample of 42 male and female young tennis players (14.0 ± 2.0 years) with more than 2 years of training experience and found that a neuromuscular and performance training program significantly improved results in the new CODS Baseline and service box speed test. Also, Lakshmikanth et al. (2018) in their study on slightly older participants (18-22 years) with undefined experience and lower playing level (college players) determined that a plyometric training program lasting 6 weeks with a frequency of only 1 training session per week significantly contributed to agility performances. What can be observed is that in this study, there is also a difference in population and program characteristics compared to the paper in the dissertation, which could be a reason for obtaining contrasting results. In line with the results of the dissertation and a more similar sample, Novak et al. (2023) in their research on the effect of a plyometric program with resistance bands found that such training, conducted over the same duration of 6 weeks but with a slightly higher frequency (2 times per week), did not have a significant effect on improving results in the RAG (WS-S) test. It is also worth noting that the program used in this research is very similar to the program in the doctoral dissertation.

In conclusion, this dissertation demonstrates the positive effects of a plyometric training program on various physical performance components (sprint speed, power, change of direction speed, and reactive agility) in healthy tennis players. Consistent with this, such plyometric training programs can induce several neuromuscular adaptations that contribute to improved athletic performance. Therefore, it can be affirmed that this doctoral study confirmed the hypothesis that a six-week plyometric training program significantly enhances results in the new TENCODS and TENRAG tests (5.9% and 6.0%, respectively) during the final testing phase of the experimental group. However, since statistically significant effects were not observed on other CODS tests, this may raise questions about the effectiveness of the new tests.

To summarize, the plyometric training program used in this research should be employed in tennis due to its potential benefits in enhancing specific physical qualities and skills required in the sport. Such results can offer valuable insights for coaches in designing diverse tennis-specific scenarios to enhance overall performance, particularly focusing on the neuromuscular fitness of their players. However, the obtained results indicate that there are some limitations in previous studies and this dissertation, that have been attempted to be explained through discussion. This opens the door for further in-depth investigations on similar topics, offering the potential for new insights and advancements in this field, particularly among young tennis players during both the early puberty and puberty phases.

GENERAL CONCLUSION

Through three studies, the research has provided valuable insights for the design and evaluation of specific tests, success factors and training program effectiveness for agility development in tennis. All research questions have been explored and answered, and all aims of this work have been achieved.

Study 1 focused on the validation of newly constructed tests for assessing change of direction speed and reactive agility. The results demonstrated a moderate level of reliability and validity for the tests, applicable to a sample of young tennis players. Study 2 investigated the correlation between anthropometric characteristics and motor abilities with change of direction speed and reactive agility in young tennis players. The results showed that there is a statistically significant correlation of agility with anthropometric characteristics, running speed tests, and horizontal explosive power variables, whereas there was no significant correlation with vertical explosive power variables. In conclusion, the results confirmed the hypothesis that there is a significant correlation between almost all anthropometric variables and motor abilities in change of direction speed and reactive agility performance in young tennis players. These findings provide coaches with useful information for developing training methods aimed at improving change of direction speed and reactive agility. Study 3 examined the effect of plyometric training on change of direction speed and reactive agility. The results showed that a six-week plyometric training program significantly improved change of direction speed and reactive agility variables measured with newly constructed tests in young competitive tennis players.

Overall, this doctoral dissertation contributes to the understanding of change of direction speed and reactive agility in tennis and provides valuable guidance for the training and development of young tennis players. Its results and recommendations can be beneficial for coaches and experts working with young tennis players to improve their motor abilities and develop specific training programs to enhance on-court performance. Ultimately, the aim is to create conditions for the development of change of direction speed and reactive agility as key factors in achieving top results in tennis and to stimulate further research and innovation in this field.

Limitations and perspectives for future research

There are a few limitations to consider when interpreting the data in this doctoral dissertation. Firstly, the newly constructed test for change of direction speed and reactive agility has a very short test duration with a limited number of changes of direction. Also, the newly constructed TENRAG test was not compared to another RAG test but rather to a CODS test. Furthermore, the quality of participants' movements, which could impact their performance, was not evaluated. In future research, it is recommended to involve expert and licensed tennis coaches to evaluate participants' movement techniques during test performance to assess the effect of this aspect on the results. Additionally, it could be beneficial to determine the level of cognitive factors, perception, and decision-making to explain the effect and association between morphology, speed, explosive power, and reactive agility (RAG). Another limitation is that the motor tests were conducted with a convenience sample of participants under controlled conditions, and the results might have differed with different test selections. This research focused only on male tennis players, and the results may not be directly applicable to female players. Therefore, for future research, it's essential to conduct tests with participants of different genders and varying competition categories to avoid potential selection bias. It's also essential to consider that the choice of tests for assessing motor abilities can affect the study outcomes. Different tests might provide varying results and introduce a degree of partiality based on test selection. Finally, presented studies did not evaluate the biological age of the participants, which is known to affect neuromuscular performance. Also, at this age, there is certainly a qualitative difference among players, which can further affect the result. A recommendation for further research could be to determine the most effective training approaches and content specific to each maturity stage in order to significantly improve neuromuscular performance in young tennis players during both the prepuberty and early puberty phases.

REFERENCES

Agostini, B. R., de Godoy Palomares, E. M., de Almeida Andrade, R., Uchoa, F. N. M., Alves, N. (2017). Analysis of the influence of plyometric training in improving the performance of athletes in rhythmic gymnastics. *Motricidade*, *13*(2), 71-80.

Ahmadi, M., Nobari, H., Ramirez-Campillo, R., Perez-Gomez, J., Ribeiro, A., Martinez-Rodriguez, A. (2021). Effects of plyometric jump training in sand or rigid surface on jump-related biomechanical variables and physical fitness in female volleyball players. *International Journal of Environmental Research and Public Health*, *18*(24), 13093.

Alemdaroglu, U. (2012). The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. *Journal of Human Kinetics*, *31*, 149-158.

Atkinson, G., Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, *26*, 217-238.

Bal, B., Kaur, P., Singh, D. (2011). Effects of a Short-Term Plyometric Training Program of Agility in Young Basketball Players. *Brazilian Journal of Biomotricity*, *5*(4), 271-278.

Bal, B., Singh, S., Dhesi, S. S., Singh, M. (2012). Effects of 6-week plyometric training on biochemical and physical fitness parameters of Indian jumpers. *Journal of Physical Education and Sport Management*, *3*(2), 35-40.

Barber-Westin, S. D., Hermet, A., Noyes, F. R. (2010). A six-week neuromuscular training program for competitive junior tennis players. *Journal of Strength and Conditioning Research*, *24*(9), 2372-2382.

Barber-Westin, S. D., Hermet, A., Noyes, F. R. (2015). A six-week neuromuscular and performance training program improves speed, agility, dynamic balance, and core endurance in junior tennis players. *Journal of Athletic Enhancement*, *4*(1), 1-8.

Bashir, S. F., Nuhmani, S., Dhall, R., Muaidi, Q. I. (2019). Effect of core training on dynamic balance and agility among Indian junior tennis players. *Journal of Back and Musculoskeletal Rehabilitation*, *32*(2), 245-252.

Baumgartner, T. A., Chung, H. (2001). Confidence limits for intraclass reliability coefficients. *Measurement in Physical Education and Exercise Science*, *5*(3), 179-188.

Behringer, M., Neuerburg, S., Matthews, M., Mester, J. (2013). Effects of two different resistance-training programs on mean tennis-serve velocity in adolescents. *Pediatric Exercise Science*, *25*(3), 370-384.

Benvenuti, C., Minganti, C., Condello, G., Capranica, L., Tessitore, A. (2010). Agility assessment in female futsal and soccer players. *Medicina*, *46*(6), 415–420.

Bland, J. M., Altman, D. G. (1997). Cronbach's alpha. *BMJ (Clinical Research)*, *314*(7080), 572.

Bogdanis, G. C., Donti, O., Papia, A., Donti, A., Apostolidis, N., Sands, W. A. (2019). Effect of plyometric training on jumping, sprinting and change of direction speed in child female athletes. *Sports*, *7*(5), 116.

Bompa, T., Haff, G. (2009). *Periodization: Theory and Methodology of Training*. Leeds: Human Kinetics.

Bouteraa, I., Negra, Y., Shephard, R. J., Chelly, M. S. (2020). Effects of combined balance and plyometric training on athletic performance in female basketball players. *Journal of Strength and Conditioning Research*, *34*(7), 1967-1973.

Brown, M. E., Mayhew, J. L., Boleach, L. W. (1986). Effect of plyometric training on vertical jump performance in high school basketball players. *Journal of Sports Medicine and Physical Fitness*, *26*(1), 1–4.

Brughelli, M., Cronin, J., Levin, G., Chaouachi, A. (2008). Understanding change of direction ability in sport a review of resistance training studies. *Sports Medicine*, *38,* 1045-1063.

Bruton, A., Conway, J. H., Holgate, S. T. (2000). Reliability: what is it, and how is it measured?. *Physiotherapy*, *86*(2), 94-99.

Chimera, N. J., Swanik, K. A., Swanik, C. B., Straub, S. J. (2004). Effects of Plyometric Training on Muscle-Activation Strategies and Performance in Female Athletes. *Journal of Athletic Training*, *39*(1), 24–31.

Chinn, S. (1991). Statistics in respiratory medicine. Repeatability and method comparison. *Thorax*, *46*(6), 454.

Chmielewski, T. L., Myer, G. D., Kauffman, D., Tillman, S. M. (2006). Plyometric exercise in the rehabilitation of athletes: physiological responses and clinical application. *Journal of Orthopaedic and Sports Physical Therapy*, *36*(5), 308-319.

Condello, G., Minganti, C., Lupo, C., Benvenuti, C., Pacini, D., Tessitore, A. (2013). Evaluation of change-of-direction movements in young rugby players. *International Journal of Sports Physiology and Performance*, *8*(1), 52–56.

Conlon, J., Haff, G. G., Nimphius, S., Tran, T., Newton, R. U. (2013). Vertical jump velocity as a determinant of speed and agility performance. *Journal of Australian Strength and Conditioning*, *21*, 88-90.

Cooke, K., Quinn, A., Sibte, N. (2011). Testing speed and agility in elite tennis players. *Strength and Conditioning Journal*, *33*(4), 69-72.

Currell, K., Jeukendrup, A. E. (2008). Validity, reliability and sensitivity of measures of sporting performance. *Sports Medicine, 38,* 297-316.

Čanaki, M., Birkić, Ž. (2009). Specifičnosti pliometrijskog treninga tenisača. *Hrvatski Športskomedicinski Vjesnik*, *24*(1), 45-50.

Davies, G., Riemann, B. L., Manske, R. (2015). Current concepts of plyometric exercise. *International Journal of Sports Physical Therapy*, *10*(6), 760–786.

Delextrat, A., Grosgeorge, B., Bieuzen, F. (2015). Determinants of performance in a new test of planned agility for young elite basketball players. *International Journal of Sports Physiology and Performance*, *10*(2), 160–165.

Deng, N., Soh, K. G., Huang, D., Abdullah, B., Luo, S., Rattanakoses, W. (2022). Effects of plyometric training on skill and physical performance in healthy tennis players: A systematic review and meta-analysis. *Frontiers in Physiology*, *13*, 1024418.

DeVellis, R. F. (2003). *Scale Development: Theory and Applications*. Thousand Oaks, CA: Sage Publications.

Erikoglu, O. G., Arslan, E. (2016). The relationships among acceleration, agility, sprinting ability, speed dribbling ability and vertical jump ability in 14-year-old soccer players. *Journal of Sports and Physical Education, 3*(2), 29-34.

Eriksson, A., Johansson, F. R., Back, M. (2015). Reliability and criterion-related validity of the 20-yard shuttle test in competitive junior tennis players. *Journal of Sports Medicine, 6*, 269-276.

Farrow, D., Young, W., Bruce, L. (2005). The development of a test of reactive agility for netball: a new methodology. *Journal of Science and Medicine in Sport*, *8*(1), 52–60.

Fathi, A., Hammami, R., Moran, J., Borji, R., Sahli, S., Rebai, H. (2019). Effect of a 16-week combined strength and plyometric training program followed by a detraining period on athletic performance in pubertal volleyball players. *Journal of Strength and Conditioning Research*, *33*(8), 2117-2127.

Fatouros, I. G., Jamurtas, A. Z., Leontsini, D., Taxildaris, K., Aggelousis, N., Kostopoulos, N., Buckenmeyer, P. J. (2000). Evaluation of Plyometric Exercise Training, Weight Training, and Their Combination on Vertical Jumping Performance and Leg Strength. *Journal of Strength and Conditioning Research*, *14*, 470–476.

Ferreira, A., Enes, C., Leao, C., Goncalves, L., Clemente, F. M., Lima, R., ... Camoes, M. (2019). Relationship between power condition, agility, and speed performance among young roller hockey elite players. *Human Movement*, *20*(1), 24-30.

Fernandez-Fernandez, J., Ulbricht, A., Ferrauti, A. (2014). Fitness testing of tennis players: how valuable is it?. *British Journal of Sports Medicine*, *48*(1), 22-31.

Fernandez-Fernandez, J., Sanz-Rivas, D., Kovacs, M. S., Moya, M. (2015). In-season effect of a combined repeated sprint and explosive strength training program on elite junior tennis players. *Journal of Strength and Conditioning Research*, *29*(2), 351-357.

Fernandez-Fernandez, J., Saez de Villarreal, E., Sanz-Rivas, D., Moya, M. (2016). The Effects of 8-Week Plyometric Training on Physical Performance in Young Tennis Players. *Pediatric Exercise Science*, *28*(1), 77–86.

Fernandez-Fernandez, J., Sanz, D., Sarabia, J. M., Moya, M. (2017). The effects of sport-specific drills training or high-intensity interval training in young tennis players. *International Journal of Sports Physiology and Performance, 12*(1), 90-98.

Fernandez-Fernandez, J., Granacher, U., Sanz-Rivas, D., Marin, J. M. S., Hernandez-Davo, J. L., Moya, M. (2018). Sequencing effects of neuromuscular training on physical fitness in youth elite tennis players. *Journal of Strength and Conditioning Research*, *32*(3), 849-856.

Fernandez-Fernandez, J., Garcia-Tormo, V., Santos-Rosa, F. J., Teixeira, A. S., Nakamura, F. Y., Granacher, U., Sanz-Rivas, D. (2020). The effect of a neuromuscular vs. dynamic warm-up on physical performance in young tennis players. *Journal of Strength and Conditioning Research*, *34*(10), 2776-2784.

Filipčič, A., Filipčič, T. (2005). The influence of tennis motor abilities and anthropometric measures on the competition successfulness of 11 and 12 year-old female tennis players. *Acta Gymnica*, *35*(2), 35-41

Gabbett T. J. (2002). Physiological characteristics of junior and senior rugby league players. *British Journal of Sports Medicine*, *36*(5), 334–339.

Gabbett, T. J., Kelly, J. N., Sheppard, J. M. (2008). Speed, change of direction speed, and reactive agility of rugby league players. *Journal of Strength and Conditioning Research*, *22*(1), 174-181.

Gabbett, T. J., Benton, D. (2009). Reactive agility of rugby league players. *Journal of Science and Medicine in Sport*, *12*(1), 212–214.

Gabbett, T. J., Jenkins, D. G., Abernethy, B. (2011). Relationships between physiological, anthropometric, and skill qualities and playing performance in professional rugby league players. *Journal of Sports Sciences, 29*(15), 1655-1664.

Gamlath, G., Thotawaththa, P. C. (2023). The Impact Of Six Weeks Of Plyometric Training Program On Agility, Explosive Power, And Acceleration Performance In Young Elite Tennis Players. *Journal of Sports and Physical Education, 10*(4), 45-53.

Gelen, E., Dede, M., Bingul, B. M., Bulgan, C., Aydin, M. (2012). Acute effects of static stretching, dynamic exercises, and high volume upper extremity plyometric activity on tennis serve performance. *Journal of Sports Science and Medicine, 11*(4), 600.

Green, B. S., Blake, C., Caulfield, B. M. (2011). A valid field test protocol of linear speed and agility in rugby union. *Journal of Strength and Conditioning Research*, *25*(5), 1256–1262.

Grosset, J. F., Piscione, J., Lambertz, D., Pérot, C. (2009). Paired changes in electromechanical delay and musculo-tendinous stiffness after endurance or plyometric training. *European Journal of Applied Physiology*, *105*, 131-139.

Haff, G. G., Triplett, N. T. (2015). *Essentials of strength training and conditioning 4th edition*. Champaign IL: Human kinetics.

Hakkukinen, K., Komi, P. V., Alen, M. (1985). Effect of explosive type strength training on isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. *Acta Physiologica Scandinavica*, *125*(4), 587-600.

Henry, G. J., Dawson, B., Lay, B. S., Young, W. B. (2013). Decision-making accuracy in reactive agility: quantifying the cost of poor decisions. *Journal of Strength and Conditioning Research*, *27*(11), 3190–3196.

Henry, G. J., Dawson, B., Lay, B. S., Young, W. B. (2016). Relationships between reactive agility movement time and unilateral vertical, horizontal and lateral jumps. *Journal of Strength and Conditioning Research, 30*(9), 2514-2521.

Hermassi, S., Fadhloun, M., Chelly, M. S., Bensbaa, A. (2011). Relationship between agility T-test and physical fitness measures as indicators of performance in elite adolescent handball players. *Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports*, *1*(5), 125-131.

Hernandez-Davo, J. L., Loturco, I., Pereira, L. A., Cesari, R., Pratdesaba, J., Madruga-Parera, M., Sanz-Rivas, D., Fernández-Fernández, J. (2021). Relationship between Sprint, Change of Direction, Jump, and Hexagon Test Performance in Young Tennis Players. *Journal of Sports Science and Medicine, 20*(2), 197–203.

Hewett, T. E., Stroupe, A. L., Nance, T. A., Noyes, F. R. (1996). Plyometric training in female athletes: decreased impact forces and increased hamstring torques. *American Journal of Sports Medicine*, *24*(6), 765-773.

Hopkins W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1–15.

Hopkins, W. G., Schabort, E. J., Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine*, *31*, 211-234.

Hopkins, W. G., Marshall, S., Batterham, A., Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine Science in Sports Exercise*, *41*(1), 3.

Hotwani, R., Dass, B., Shedge, S., Bhatnagar, A. (2021). Effectiveness of speed and plyometric training on agility in lawn tennis players. *Annals of the Romanian Society for Cell Biology*, *25*(6), 18557-18569.

Huang, P. Y., Jankaew, A., Lin, C. F. (2021). Effects of plyometric and balance training on neuromuscular control of recreational athletes with functional ankle instability: a randomized controlled laboratory study. *International Journal of Environmental Research and Public Health*, *18*(10), 5269.

Huggins, J., Jarvis, P., Brazier, J., Kyriacou, Y., Bishop, C. (2017). Within-and between-session reliability of the spider drill test to assess Change of Direction Speed in youth tennis athletes. *International Journal of Sports and Exercise Medicine, 3*, 1-6.

Impellizzeri, F. M., Marcora, S. M. (2009). Test validation in sport physiology: lessons learned from clinimetrics. *International Journal of Sports Physiology and Performance*, *4*(2), 269-277.

Jansen, M. G. T., Huijgen, B. C., Faber, I. R., Elferink-Gemser, M. T. (2021a). Measuring Agility in Tennis, Badminton, and Squash: A Systematic Review. *Strength and Conditioning Journal, 43*, 53-67.

Jansen, M. G. T., Elferink-Gemser, M. T., Hoekstra, A. E., Faber, I. R., Huijgen, B. C. H. (2021b). Design of a Tennis-Specific Agility Test (TAT) for Monitoring Tennis Players. *Journal of Human Kinetics, 80,* 239–250.

Jeffriess, M. D., Schultz, A. B., McGann, T. S., Callaghan, S. J., Lockie, R. G. (2015). Effects of preventative ankle taping on planned change-of-direction and reactive agility performance and ankle muscle activity in basketballers. *Journal of Sports Science and Medicine*, *14*(4), 864.

Jlid, M. C., Coquart, J., Maffulli, N., Paillard, T., Bisciotti, G. N., Chamari, K. (2020). Effects of in season multi-directional plyometric training on vertical jump performance, change of direction speed and dynamic postural control in U-21 soccer Players. *Frontiers in Physiology*, *11*, 374.

Kanabar, H., Gajjar, R., Patel, G. (2022). Effect of plyometric training and agility ladder training on agility, speed and jump performance in tennis players. *Parul University Journal of Health Sciences and Research*, *1*(1), 32-38.

Kato, T., Terashima, T., Yamashita, T., Hatanaka, Y., Honda, A., Umemura, Y. (2006). Effect of low-repetition jump training on bone mineral density in young women. *Journal of Applied Physiology*, *100*(3), 839-843.

Khlifa, R., Aouadi, R., Hermassi, S., Chelly, M. S., Jlid, M. C., Hbacha, H., Castagna, C. (2010). Effects of a plyometric training program with and without added load on jumping ability in basketball players. *Journal of Strength and Conditioning Research, 24*(11), 2955–2961.

Kilit, B., Arslan, E. (2019). Effects of High-Intensity Interval Training vs. On-Court Tennis Training in Young Tennis Players. *Journal of Strength and Conditioning Research*, *33*(1), 188–196.

Kim, S., Rhi, S. Y., Kim, J., Chung, J. S. (2022). Plyometric training effects on physical fitness and muscle damage in high school baseball players. *Physical Activity and Nutrition*, *26*(1), 1.

Knoop, M., Fernandez-Fernandez, J., Ferrauti, A. (2013). Evaluation of a specific reaction and action speed test for the soccer goalkeeper. *Journal of Strength and Conditioning Research*, *27*(8), 2141–2148.

Koklu, Y., Alemdaroglu, U., Ozkan, A., Koz, M., Ersoz, G. (2015). The relationship between sprint ability, agility and vertical jump performance in young soccer players. *Science and Sports*, *30*(1), 1-5.

Komal, M., Singh, T. N. (2013). Effect of eight weeks plyometric training on the performance of national level female basketball players. *International Journal of Management, Economics and Social Sciences*, *2*(2), 51-53.

Koo, T. K., Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155–163.

Kosova, S., Beyhan, R., Kosova, M. K. (2022). The effect of 8-week plyometric training on jump height, agility, speed and asymmetry. *Pedagogy of Physical Culture and Sports*, *26*(1), 13-18.

Kraemer, W. J., Hakkinen, K., Triplett-McBride, N. T., Fry, A. C., Koziris, L. P., Ratamess, N. A., ... Knuttgen, H. G. (2003). Physiological changes with periodized resistance training in women tennis players. *Medicine and Science in Sports and Exercise*, *35*(1), 157-168.

Kramer, T., Huijgen, B. C., Elferink-Gemser, M. T., Visscher, C. (2017). Prediction of Tennis Performance in Junior Elite Tennis Players. *Journal of Sports Science and Medicine*, *16*(1), 14–21.

Krolo, A., Gilic, B., Foretic, N., Pojskic, H., Hammami, R., Spasic, M., Uljevic, O., Versic, S., Sekulic, D. (2020). Agility Testing in Youth Football (Soccer) Players; Evaluating Reliability, Validity and Correlates of Newly Developed Testing Protocols. *International Journal of Environmental Research and Public Health*, *17*(1), 294.

Kubo, K., Morimoto, M., Komuro, T., Yata, H., Tsunoda, N., Kanehisa, H., Fukunaga, T. (2007). Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Medicine and Science in Sports and Exercise, 39*(10), 1801-1810.

Kumar, S. (2017). Relationships between physical characteristics and ranking of young tennis players. *International Journal of Physical Education, Sports and Health*, *4*, 60-64.

Lakshmikanth, V. P., Paul, J., Ebenezer, B., Ramanthan. (2018). Effects of plyometric training and conventional training on agility performance in tennis players. *International Journal of Medical and Exercise Science, 4*(3), 492-499.

Lee, K. M., Lee, J., Chung, C. Y., Ahn, S., Sung, K. H., Kim, T. W., ... Park, M. S. (2012). Pitfalls and important issues in testing reliability using intraclass correlation coefficients in orthopaedic research. *Clinics in Orthopedic Surgery*, *4*(2), 149-155.

Leone, M., Comtois, A. S., Tremblay, F., Léger, L. (2006). Specificity of running speed and agility in competitive junior tennis players. *Journal of Medicine and Science in Tennis, 11*, 10–11.

Li, F., Wang, R., Newton, R. U., Sutton, D., Shi, Y., Ding, H. (2019). Effects of complex training versus heavy resistance training on neuromuscular adaptation, running economy and 5-km performance in well-trained distance runners. *PeerJ*, *7*, e6787.

Little, T., Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *Journal of Strength and Conditioning Research*, *19*(1), 76–78.

Lockie, R. G., Jeffriess, M. D., McGann, T. S., Callaghan, S. J., Schultz, A. B. (2014). Planned and reactive agility performance in semiprofessional and amateur basketball players. *International Journal of Sports Physiology and Performance*, *9*(5), 766–771.

Loureiro, L. F. B., Freitas, P. B. (2016). Development of an agility test for badminton players and assessment of its validity and test–retest reliability. *International Journal of Sports Physiology and Performance, 11*(3), 305-310.

Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., ... Garrett, W. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *American Journal of Sports Medicine*, *33*(7), 1003-1010.

Markovic, G., Jukic, I., Milanovic, D., Metikos, D. (2007). Effects of sprint and plyometric training on muscle function and athletic performance. *Journal of Strength and Conditioning Research*, *21*(2), 543–549.

Markovic, G., Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine*, *40*(10), 859–895.

Marković, G., Sekulić, D., Marković, M. (2007). Is agility related to strength qualities? Analysis in latent space. *Collegium Antropologicum*, *31*(3), 787–793.

Matavulj, D., Kukolj, M., Ugarkovic, D., Tihanyi, J., Jaric, S. (2001). Effects of pylometric training on jumping performance in junior basketball players. *Journal of Sports Medicine and Physical Fitness*, *41*(2), 159-164.

Mayhew, J. L., Piper, F. C., Schwegler, T. M., Ball, T. E. (1989). Contributions of speed, agility and body composition to anaerobic power measurement in college football players. *Journal of Strength and Conditioning Research*, *3*(4), 101-106

Meir, R., Newton, R., Curtis, E., Fardell, M., Butler, B. (2001). Physical fitness qualities of professional rugby league football players: determination of positional differences. *Journal of Strength and Conditioning Research*, *15*(4), 450-458.

Mejovšek, M. (2003). *Uvod u metode znanstvenog istraživanja u društvenim i humanističkim znanostima*. Naklada Slap.

Miller, J. M., Hilbert, S. C., Brown, L. E. (2001). Speed, quickness, and agility training for senior tennis players. *Strength and Conditioning Journal*, *23*(5), 62.

Mohanta, N., Kalra, S., Pawaria, S. (2019). A Comparative Study of Circuit Training and Plyometric Training on Strength, Speed and Agility in State Level Lawn Tennis Players. *Journal of Clinical and Diagnostic Research*, *13*(12), 5-10.

Morland, B., Bottoms, L., Sinclair, J., Bourne, N. (2013). Can change of direction speed and reactive agility differentiate female hockey players?. *International Journal of Performance Analysis in Sport*, *13*(2), 510-521.

Moya-Ramon, M., Nakamura, F. Y., Teixeira, A. S., Granacher, U., Santos-Rosa, F. J., Sanz-Rivas, D., Fernandez-Fernandez, J. (2020). Effects of resisted vs. conventional sprint training on physical fitness in young elite tennis players. *Journal of Human Kinetics*, *73*(1), 181-192.

Munivrana, G., Filipčić, A., Filipčić, T. (2015). Relationship of Speed, Agility, Neuromuscular Power, and Selected Anthropometrical Variables and Performance Results of Male and Female Junior Tennis Players. *Collegium Antropologicum*, *39* (1), 109-116.

Munivrana, G., Jelaska, I., Tomljanović, M. (2022). Design and Validation of a New Tennis-Specific Reactive Agility Test-A Pilot Study. *International Journal of Environmental Research and Public Health*, *19*(16), 10039.

Myburgh, G. K., Cumming, S. P., Silva, M. C., Cooke, K., Malina, R. M. (2016). Maturity-Associated Variation in Functional Characteristics Of Elite Youth Tennis Players. *Pediatric Exercise Science*, *28*(4), 542–552.

Myklebust, G., Engebretsen, L., Braekken, I. H., Skjolberg, A., Olsen, O. E., Bahr, R. (2003). Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clinical Journal of Sport Medicine*, *13*(2), 71-78.

Negra, Y., Chaabene, H., Hammami, M., Amara, S., Sammoud, S., Mkaouer, B., Hachana, Y. (2017). Agility in Young Athletes: Is It a Different Ability From Speed and Power?. *Journal of Strength and Conditioning Research*, *31*(3), 727–735.

Nimphius, S., McGuigan, M. R., Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research*, *24*(4), 885-895.

Novak, D., Lončar, I., Sinković, F., Barbaros, P., Milanović, L. (2023). Effects of Plyometric Training with Resistance Bands on Neuromuscular Characteristics in Junior Tennis Players. *International Journal of Environmental Research and Public Health*, *20*(2), 1085.

Olcucu, B., Erdil, G., Altinkok, M. (2013). Evaluation of the effect of Plyometric exercises on the speed of the ball and the hitting percentage during a service. *Nigde University Journal of Physical Education and Sport Sciences, 7*(1), 48-59.

Paul, D. J., Gabbett, T. J., Nassis, G. P. (2016). Agility in Team Sports: Testing, Training and Factors Affecting Performance. *Sports Medicine, 46*(3), 421–442.

Pauole, K., Madole, K., Garhammer, J., Lacourse, M., Rozenek, R. (2000). Reliability and validity of the T-test as a measure of agility, leg power, and leg speed in college-aged men and women. *Journal of Strength and Conditioning Research, 14*(4), 443-450.

Pearson, A. (2001). *Speed, Agility and Quickness for Soccer*. London: A&C Black.

Pehar, M., Sisic, N., Sekulic, D., Coh, M., Uljevic, O., Spasic, M., Krolo, A., Idrizovic, K. (2018). Analyzing the relationship between anthropometric and motor indices with basketball specific pre-planned and non-planned agility performances. *Journal of Sports Medicine and Physical Fitness*, *58*(7), 1037–1044.

Pereira, L. A., Nimphius, S., Kobal, R., Kitamura, K., Turisco, L. A. L., Orsi, R. C., Cal Abad, C. C., Loturco, I. (2018). Relationship Between Change of Direction, Speed, and Power in Male and Female National Olympic Team Handball Athletes. *Journal of Strength and Conditioning Research*, *32*(10), 2987–2994.

Peric, M., Zenic, N., Mandic, G. F., Sekulic, D., Sajber, D. (2012). The reliability, validity and applicability of two sport-specific power tests in synchronized swimming. *Journal of Human Kinetics*, *32*, 135–145.

Peric, I., Spasic, M., Novak, D., Ostojic, S., Sekulic, D. (2021). Pre-Planned and Non-Planned Agility in Patients Ongoing Rehabilitation after Knee Surgery: Design, Reliability and Validity of the Newly Developed Testing Protocols. *Diagnostics, 11*(1), 146-161.

Petersen, W., Braun, C., Bock, W., Schmidt, K., Weimann, A., Drescher, W., ... Zantop, T. (2005). A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Archives of Orthopaedic and Trauma Surgery*, *125*, 614-621.

Pojskic, H., Pagaduan, J., Uzicanin, E., Separovic, V., Spasic, M., Foretic, N., Sekulic, D. (2019). Reliability, Validity and Usefulness of a New Response Time Test for Agility-Based Sports: A Simple vs. Complex Motor Task. *Journal of Sports Science and Medicine*, *18*(4), 623–635.

Portney, L. G., Watkins, M. P. (2009). *Foundations of clinical research: applications to practice*. NJ: Pearson/Prentice Hall.

Rameshkannan, S., Chittibabu, B. (2014). Effect of plyometric training on agility performance of male handball players. *International Journal of Physical Education, Fitness and Sports, 3*(4), 72-76.

Ramirez-Campillo, R., Meylan, C., Alvarez, C., Henríquez-Olguín, C., Martínez, C., Cañas-Jamett, R., Andrade, D. C., Izquierdo, M. (2014). Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. *Journal of Strength and Conditioning Research*, *28*(5), 1335–1342.

Ramirez-Campillo, R., Burgos, C. H., Henríquez-Olguín, C., Andrade, D. C., Martínez, C., Álvarez, C., Castro-Sepúlveda, M., Marques, M. C., Izquierdo, M. (2015). Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *Journal of Strength and Conditioning Research*, *29*(5), 1317–1328.

Ramirez-Campillo, R., Sanchez-Sanchez, J., Romero-Moraleda, B., Yanci, J., García-Hermoso, A., Manuel Clemente, F. (2020a). Effects of plyometric jump training in female soccer player's vertical jump height: A systematic review with meta-analysis. *Journal of Sports Sciences*, *38*(13), 1475-1487.

Ramirez-Campillo, R., Castillo, D., Raya-González, J., Moran, J., de Villarreal, E. S., Lloyd, R. S. (2020b). Effects of plyometric jump training on jump and sprint performance in young male soccer players: a systematic review and meta-analysis. *Sports Medicine*, *50*, 2125-2143.

Ramirez-Campillo, R., García-Hermoso, A., Moran, J., Chaabene, H., Negra, Y., Scanlan, A. T. (2021a). The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. *Journal of Sport and Health Science, 11*(6), 656-670.

Ramirez-Campillo, R., García-de-Alcaraz, A., Chaabene, H., Moran, J., Negra, Y., Granacher, U. (2021b). Effects of plyometric jump training on physical fitness in amateur and professional volleyball: a meta-analysis. *Frontiers in Physiology*, *12*, 636140.

Ramos, A., Vale, P., Salgado, B., Correia, P., Oliveira, E., Seabra, A., Rebelo, A., Brito, J. (2009). *Physical test performance of elite portuguese junior soccer players according to positional roles.* London: Routledge.

Rathore, M. S. (2016). Effects of Plyometric Training and Resistance Trainng on Agility of Tennis Players. *Indian Journal of Physical Education, Sports Medicine and Exercise Science, 16*(1), 32-34.

Rojano Ortega, D., Berral-Aguilar, A. J., Berral de la Rosa, F. J. (2022). Kinetics and vertical stiffness of female volleyball players: Effect of low-intensity plyometric training. *Research Quarterly for Exercise and Sport*, *93*(4), 734-740.

Romero, C., Ramirez-Campillo, R., Alvarez, C., Moran, J., Slimani, M., Gonzalez, J., Banzer, W. E. (2021). Effects of maturation on physical fitness adaptations to plyometric jump training in youth females. *Journal of Strength and Conditioning Research*, *35*(10), 2870-2877.

Saez de Villarreal, E., Molina, J. G., de Castro-Maqueda, G., Gutiérrez-Manzanedo, J. V. (2021). Effects of plyometric, strength and change of direction training on high-school basketball player's physical fitness. *Journal of Human Kinetics*, *78*(1), 175-186.

Salonikidis, K., Zafeiridis, A. (2008). The effects of plyometric, tennis-drills and combined training on reaction, lateral and linear speed, power and strength in novice tennis players. *Journal of Strength and Conditioning Research*, *22*(1), 182–191.

Sannicandro, I., Cofano, G., Rosa, R. A., Piccinno, A. (2014). Balance training exercises decrease lower-limb strength asymmetry in young tennis players. *Journal of Sports Science and Medicine*, *13*(2), 397.

Sattler, T., Sekulic, D., Hadzic, V., Uljevic, O., Dervisevic, E. (2012). Vertical jumping tests in volleyball: reliability, validity, and playing-position specifics. *Journal of Strength and Conditioning Research*, *26*(6), 1532-1538.

Sattler, T., Sekulić, D., Spasić, M., Perić, M., Krolo, A., Uljević, O., Kondrič, M. (2015). Analysis of the Association Between Motor and Anthropometric Variables with Change of Direction Speed and Reactive Agility Performance. *Journal of Human Kinetics, 47*, 137–145.

Saunders, P. U., Telford, R. D., Pyne, D. B., Peltola, E. M., Cunningham, R. B., Gore, C. J., Hawley, J. A. (2006). Short-term plyometric training improves running economy in highly trained middle and long distance runners. *Journal of Strength and Conditioning Research*, *20*(4), 947-954.

Scanlan, A., Humphries, B., Tucker, P. S., Dalbo, V. (2014). The influence of physical and cognitive factors on reactive agility performance in men basketball players. *Journal of Sports Sciences*, *32*(4), 367-374.

Scanlan, A. T., Tucker, P. S., Dalbo, V. J. (2015). The importance of open-and closed-skill agility for team selection of adult male basketball players. *Journal of Sports Medicine and Physical Fitness*, *55*(5), 390-396.

Sekulić, D., Foretic, N., Gilic, B., Esco, M. R., Hammami, R., Uljevic, O., Versic, S., Spasic, M. (2019). Importance of Agility Performance in Professional Futsal Players; Reliability and Applicability of Newly Developed Testing Protocols. *International Journal of Environmental Research and Public Health*, *16*(18), 3246.

Sekulić, D., Metikoš, D. (2007). *Osnove transformacijskih postupaka u kineziologiji: uvod u osnovne kineziološke transformacije*. Split: Fakultet prirodoslovno-matematičkih znanosti i kineziologije.

Sekulić, D., Pehar, M., Krolo, A., Spasic, M., Uljevic, O., Calleja-González, J., Sattler, T. (2017). Evaluation of Basketball-Specific Agility: Applicability of Preplanned and Nonplanned Agility Performances for Differentiating Playing Positions and Playing Levels. *Journal of Strength and Conditioning Research*, *31*(8), 2278–2288.

Sekulic, D., Pojskic, H., Zeljko, I., Pehar, M., Modric, T., Versic, S., Novak, D. (2021). Physiological and Anthropometric Determinants of Performance Levels in Professional Futsal. *Frontiers in Psychology*, *11*, 621763.

Sheppard, J. M., Young, W. B., Doyle, T. L. A., Sheppard, T. A., Newton, R. U. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *Journal of Science and Medicine in Sport, 9*(4), 342-349.

Sheppard, J. M., Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, *24*(9), 919–932.

Silva, A. F., Clemente, F. M., Lima, R., Nikolaidis, P. T., Rosemann, T., Knechtle, B. (2019). The effect of plyometric training in volleyball players: A systematic review. *International Journal of Environmental Research and Public Health*, *16*(16), 2960.

Sinković, F., Foretić, N., Novak, D. (2022). Reliability, Validity and Sensitivity of Newly Developed Tennis-Specific Reactive Agility Tests. *Sustainability*, *14*(20), 13321.

Sinković, F., Novak, D., Foretić, N. (2023). The Association between Morphology, Speed, Power and Agility in Young Tennis Players. *Collegium Antropologicum*, *47*(1), 61-65.

Sinković, F., Novak, D., Foretić, N., Kim, J., Subramanian, S.V. (2023). The plyometric treatment effects on change of direction speed and reactive agility in young tennis players: a randomized controlled trial. *Frontiers in Physiology*, *14*, 1226831.

Sinkovic, F., Novak, D., Foretic, N., Zemková, E. (2023). The Effects of Biological Age on Speed-Explosive Properties in Young Tennis Players. *Journal of Functional Morphology and Kinesiology*, *8*(2), 48.

Sisic, N., Jelicic, M., Pehar, M., Spasic, M., Sekulic, D. (2016). Agility performance in high-level junior basketball players: the predictive value of anthropometrics and power qualities. *Journal of Sports Medicine and Physical fitness*, *56*(7), 884–893.

Sole, S., Ramírez-Campillo, R., Andrade, D. C., Sanchez-Sanchez, J. (2021). Plyometric jump training effects on the physical fitness of individual-sport athletes: A systematic review with meta-analysis. *PeerJ*, *9*, e11004.

Spasic, M., Krolo, A., Zenic, N., Delextrat, A., Sekulic, D. (2015). Reactive Agility Performance in Handball; Development and Evaluation of a Sport-Specific Measurement Protocol. *Journal of Sports Science and Medicine*, *14*(3), 501–506.

Spaniol, F., Flores, J., Bonnette, R., Melrose, D., Ocker, L. (2010). The relationship between speed and agility of professional arena league football players. *Journal of Strength and Conditioning Research*, *24,* 1.

Spierer, D. K., Petersen, R. A., Duffy, K., Corcoran, B. M., Rawls-Martin, T. (2010). Gender influence on response time to sensory stimuli. *Journal of Strength and Conditioning Research*, *24*(4), 957-963.

Spiteri, T., Nimphius, S., Hart, N. H., Specos, C., Sheppard, J. M., Newton, R. U. (2014). Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *Journal of Strength and Conditioning Research*, *28*(9), 2415-2423.

Sporiš, G., Milanović, Z., Trajković, N., Joksimović, A. (2011). Correlation between speed, agility and quickness (SAQ) in elite young soccer players. *Acta Kinesiologica*, *5*(2), 36-41.

Spurrs, R. W., Murphy, A. J., Watsford, M. L. (2003). The effect of plyometric training on distance running performance. *European Journal of Applied Physiology*, *89*(1), 1–7.

Taber, K. S. (2018). The use of Cronbach’s alpha when developing and reporting research instruments in science education. *Research in Science Education*, *48*, 1273-1296.

Tammam, A. H., Hashem, E. M. (2020). The individual and combined effects of PNF stretching and plyometric training on muscular power and flexibility for volleyball players. *Amazonia Investiga*, *9*(36), 73-82.

Tavakol, M., Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2,* 53–55.

Terraza-Rebollo, M., Baiget, E., Corbi, F., Planas Anzano, A. (2017). Effects of Strength Training on Hitting Speed in Young Tennis Players. *International Journal of Medicine and Science of Physical Activity and Sport*, *17*(66), 349-366.

Thomas, J.R., Nelson, J.K. (2001). *Research methods in physical activity* (4th ed.). Champaign (IL): Human Kinetics.

Trecroci, A., Milanović, Z., Rossi, A., Broggi, M., Formenti, D., Alberti, G. (2016). Agility profile in sub-elite under-11 soccer players: is SAQ training adequate to improve sprint, change of direction speed and reactive agility performance?. *Research in Sports Medicine*, *24*(4), 331–340.

Ulbricht, A., Fernandez-Fernandez, J., Mendez-Villanueva, A., Ferrauti, A. (2016). Impact of Fitness Characteristics on Tennis Performance in Elite Junior Tennis Players. *Journal of Strength and Conditioning Research*, *30*(4), 989–998.

Vescovi, J. D., McGuigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *Journal of Sports Sciences*, *26*(1), 97–107.

Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., Petrovic, P. (2012). Executive Functions Predict the Success of Top-Soccer Players. *PLoS ONE, 7*(4), 34731.

Villarejo-García, D. H., Moreno-Villanueva, A., Soler-López, A., Reche-Soto, P., Pino-Ortega, J. (2023). Use, Validity and Reliability of Inertial Movement Units in Volleyball: Systematic Review of the Scientific Literature. *Sensors*, *23*(8), 3960.

Vincent W. J. (2005). *Statistics in kinesiology* (3rd ed.). Champaign (IL): Human Kinetics.

Vuong, J. L., Fett, J., Ulbricht, A., Ferrauti, A. (2022). Physical determinants, intercorrelations and relevance of movement speed components in elite junior tennis players. *European Journal of Sport Science*, *22*(12), 1805–1815.

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research*, *19*(1), 231-240.

Weir, J. P., Vincent, W. J. (2020). *Statistics in Kinesiology* (5th ed.). Champaign (IL): Human Kinetics.

Wheeler, K. W., Sayers, M. G. (2010). Modification of agility running technique in reaction to a defender in rugby union. *Journal of Sports Science and Medicine*, *9*(3), 445–451.

Wilk, K. E., Voight, M. L., Keirns, M. A., Gambetta, V., Andrews, J. R., Dillman, C. J. (1993). Stretch-shortening drills for the upper extremities: theory and clinical application. *Journal of Orthopaedic and Sports Physical Therapy*, *17*(5), 225-239.

Wisnu-Nugroho, T., Abdul, A., Fauzi, H. Y. (2022). Validity and Reliability of Reactive Agility Measurements of Tennis Performance. *International Journal of Human Movement and Sports Sciences, 10*(2), 338 - 342.

Witzke, K. A., Snow, C. M. (2000). Effects of polymetric jump training on bone mass in adolescent girls. *Medicine and Science in Sports and Exercise*, *32*(6), 1051-1057.

Young, W. B., Hawken, M., McDonald, L. (1996). Relationship between speed, agility, and strength qualities in Australian Rules football. *Strength Conditioning Coach, 4*, 3-6.

Young, W. B., James, R., Montgomery, I. (2002). Is muscle power related to running speed with changes of direction?. *Journal of Sports Medicine and Physical Fitness*, *42*(3), 282–288.

Zeljko, I., Gilic, B., Sekulic, D. (2020). Validity, reliability and correlates of futsal- specific pre-planned and non-planned agility testing protocols. *Kinesiologia Slovenica*, *26*(2), 25–34.

Zemková, E., Hamar, D. (2014). Agility performance in athletes of different sport specializations. *Acta Gymnica*, *44*(3), 133-140.

Ziagkas, E., Zilidou, V. I., Loukovitis, A., Politopoulos, N., Douka, S., Tsiatsos, T. (2019). The Effects of 8-Week Plyometric Training on Tennis Agility Performance, Improving Evaluation Throw the Makey Makey. *Advances in Intelligent Systems and Computing*, *917,* 280-286.

Zouhal, H., Abderrahman, A. B., Dupont, G., Truptin, P., Le Bris, R., Le Postec, E., Coppalle, S., Ravé, G., Brughelli, M., Bideau, B. (2018). Laterality Influences Agility Performance in Elite Soccer Players. *Frontiers in Physiology, 9*, 807.