Pre-planned and Reactive Agility in Puberty and Early Puberty Children; Standardization of Measurement, Prediction, and Development

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DOCTORAL THESIS

Mentor:

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PREDPLANIRANA I REAKTIVNA AGILNOST KOD DJECE U PUBERTETU I RANOM PUBERTETU; OBJEKTIVIZACIJA MJERENJA, PREDIKCIJA I RAZVOJ

DOKTORSKA DISERTACIJA

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Split, 2024

PODACI O MENTORU

Doc.dr.sc. Nikola Foretić: predstojnik Zavoda za kineziološku edukaciju i metodologiju.

Rođen je 1980. u Splitu. Osnovnu školu završio je u Hvaru a srednju školu u Splitu. Diplomirao je 2003. na Fakultetu prirodoslovno-matematičkih znanosti i kineziologije Sveučilišta u Splitu te doktorirao 2012. na Kineziološkom fakultetu Sveučilišta u Splitu.

Na radno mjesto asistenta zaposlen je 2006. a docenta 2020 godine.

Sunositelj je predmeta OKT 1 i 2.

Obnaša dužnosti predstojnik Zavoda za kineziološku edukaciju i metodologiju, te predsjednika Etičkog povjerenstva.

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SADRŽAJ

SAŽETAK

Nekoliko je glavnih ciljeva ove doktorske disertacije; utvrditi prediktore pred-planirane agilnosti (CODS) i reaktivne agilnosti (RAG), razviti i validirati test za procjenu pred-planirane i reaktivne agilnosti te istražiti utjecaj/povezanost kognitivnih sposobnosti na reaktivnu agilnost. Svi navedeni ciljevi rijetko su istraživani kod djece u predpubertetu i ranom pubertetu. Posebno nisu istraživani kod one djece koja nisu odabrali specifičan sport i uz to čije se kretne strukture bitno razlikuju od kretnji koje se koriste prilikom izvođenja novo-konstruiranog testa agilnosti. Ova disertacija sastoji se od četiri studije.

Cilj prve studije bio je procijeniti mogu li brzina, snaga, pokretljivost i ravnoteža, kao i nekoliko antropometrijskih mjera, biti prediktori agilnosti u dječaka i djevojčica u ranom pubertetu. Svrha druge studije bila je konstrukcija i validacija novorazvijenog testa agilnosti koji mjeri performanse RAG-a kod školske djece. Glavni cilj treće studije bio je utvrditi povezanost između antropometrijskih pokazatelja (sastava tijela), motoričkih sposobnosti i RAG-a u dječaka i djevojčica u ranom pubertetu. Glavni cilj četvrtog istraživanja bio je istražiti povezanost između kognitivnih kapaciteta, mjerenih Stroop testom, kao eksplorativne varijable i procjene reaktivne agilnosti (RAG) kao kriterija, kod dječaka i djevojčica u pubertetu.

Ispitanici na kojima je provedeno istraživanje su djeca šestih, sedmih i osmih razreda iz iste osnovne škole u Splitu. Podaci su prikupljeni tijekom sata TZK uz suradnju profesora, dozvolu ravnatelja i suglasnost roditelja. Primijenjene su tri grupe testova: antropometrijske karakteristike, motoričke sposobnosti i kognitivne sposobnosti. Antropometrijske karakteristike uključuju tjelesnu visinu (BH), masu tijela (BM), potkožno masno tkivo (BFat) i sjedeću visinu (SH). Motoričke sposobnosti obuhvaćaju 10 metara sprint (S10), 20 metara sprint (S20), test 20 jardi (20YBP), Trokut test pred-planirane agilnosti (TCODS), Trokut test reaktivne agilnosti (TRAG), T-test, ZigZag test, skok u dalj (BJ), skok bez pripreme (engl. Squat Jump - SJ), skok s pripremom (engl. Countermovement Jump - CMJ), propadajući skok (engl. Drop Jump - DJH), te testove ravnoteže i mobilnosti. Kognitivne sposobnosti testirane su Stroop testom.

Glavni rezultati prve studije pokazalli su: (1) sprint na 10 metara pokazao se kao najvažniji prediktor pred-planirane agilnosti, (2) tjelesna masa i vertikalni skok pokazali su se kao prediktori Zig-Zag testa agilnosti u muškoj skupini. Dodatno, jedini značajan prediktor u ženskoj skupini bio je S10 za sva tri testa pred-planirane agilnosti.

Glavni rezultati druge studije pokazali su da novodizajnirani testovi reaktivne agilnosti: (1) imaju dobru osjetljivost (skew = 1.14; kurt = 3.34), (2) novodizajnirani testovi reaktivne agilnosti imaju prosječnu

pouzdanost (Inter-item korelacija: 0.32-0.55; Crombach's alpha: 0.58–0.78) i (3) novodizajnirani testovi reaktivne agilnosti imaju dobru homogenost (F: 0.07 (m), 0.13 (ž); p: 0.93 (m), 0.88 (ž)). Konstruirani TRAG test čini se pouzdanim instrumentom za mjerenje reaktivne agilnosti kod dječaka i djevojčica u pubertetu.

Glavni rezultati treće studije pokazali su da antropometriske karakteristike ispitanika nisu bile u korelaciji s TRAG. Nadalje, multivarijatna analiza dokazala je TCODS kao jedini značajan multivarijatni prediktor TRAG-a u dječaka. U međuvremenu, kod djevojčica, uz TCODS, snaga nogu je istaknuta kao značajan multivarijatni prediktor.

Glavni rezultati četvrte studije pokazali su da: (1) kognitivne sposobnosti, mjerene Stroop testom, nisu pouzdan podatak za predviđanje rezultata na TRAG testu kod učenika u pubertetu, (2) eksplozivna snaga značajan je prediktor generičke reaktivne agilnosti isključivo u uzorku dječaka, (3) CODS je jedina varijabla koja se može koristiti kao prediktor generičke reaktivne agilnosti u pubertetu.

Rezultati ove disertacije pružaju uvid u kompleksnost agilnosti kod djece u predpubertetu i ranom pubertetu, posebno u vezi s prediktorima pred-planirane agilnosti (CODS) i reaktivne agilnosti (RAG). Disertacija je pokazala da je brzina najvažniji prediktor agilnosti, dok antropometrijske mjere, ravnoteža, snaga i mobilnost nisu pouzdani prediktori agilnosti kod djece u ranom pubertetu. Validirani su novi testovi za procjenu RAG-a, koji su pokazali dobru pouzdanost i homogenost. Osim toga, rezultati su otkrili da kognitivne sposobnosti, mjereni Stroop testom, nisu pouzdani prediktori RAG-a, dok su skokovi i CODS važni prediktori za dječake i djevojčice. Ograničenja studije uključuju nedostatak uključenja drugih sposobnosti kao koordinacije i fleksibilnosti. Buduća istraživanja trebaju uključiti specifičnije testove agilnosti te razmotriti razlike između djece koja su uključena u sportske aktivnosti i onih koji nisu. Rezultati sugeriraju da je agilnost kompleksna sposobnost koja zahtijeva opsežna istraživanja, procjenu i trening kod djece u ranom pubertetu.

OSNOVNA STRUKTURA DISERTACIJE

Ovaj doktorski rad sastoji se od četiri objavljene znanstvene studije:

1. Pavlinović, V., Spasić, M., Foretić, N., Kontić, D., & Zenić, N. (2022). Differential Influence of General Anthropometric and Motor Predictors on Pre-planned Agility in Pubescent Boys and Girls: A Multiple Regression Study. Sport Mont, 20(2).
2. Pavlinović, V., Cota, Ž., Mandić, A., Škomrlj, J., & Foretić N.(2022). Construction and Validation of Newly Developed Triangle Test of Reactive Agility in School Children. Studia sportiva 16.2: 127-133.
3. Pavlinovic, V., Foretic, N., Versic, S., Sekulic, D., & Liposek, S. (2022). Predictors of Reactive Agility in Early Puberty: A Multiple Regression Gender-Stratified Study. Children, 9(11), 1780.
4. Pavlinović, V., Foretić, N., Kovačević, N., Galić, T., Lušić Kalcina, L., Mihanović, F., & Modric, T. (2024). Cognitive and Motor Capacities Are Poorly Correlated with Agility in Early Pubertal Children: Gender-Stratified Analysis. Applied Sciences, 14(8), 3148.

Radovi su nastali uz potporu Hrvatske zaklade za znanost, rad na HRZZ projektu „Projekt razvoja karijera mladih istraživača – izobrazba novih doktora znanosti“ (DOK-2021-02) pod nazivom „Predplanirana i reaktivna agilnost; razvoj i validacija specifičnih metoda mjerenja, utvrđivanje faktora utjecaja i učinkovitost transformacijskih postupaka“ (IP-2018-01-8330)

1. UVOD

1.1 Definicija agilnosti

Agilnost se općenito definira kao sposobnost brzog i efikasnog mijenjanja smjera ili brzine tijela kao odgovor na vanjski podražaj. Ova sposobnost uključuje kombinaciju većeg broja motoričkih sposobnosti, poput snage, brzine, ravnoteže i koordinacije te kognitivnih komponenti, kao što su vizualno skeniranje i anticipacija (J. Sheppard, Young, Doyle, Sheppard, i Newton, 2006; J. M. Sheppard i Young, 2006). Agilnost omogućuje pojedincu da brzo reagira na različite podražaje i prilagodi položaj tijela kako bi izveo željene pokrete (Pojskic i sur., 2019).

Uz to što je široko priznata kao važna motorička sposobnost, izazov u proučavanju agilnosti predstavlja i nedostatak univerzalno prihvaćene definicije. Različiti znanstvenici primjenjuju pojam agilnosti na različite sportske kontekste, što dodatno komplicira razumijevanje i klasifikaciju njenih komponenti (Paul, Gabbett, i Nassis, 2016). Moguće je da ovo neslaganje proizlazi zbog različitih profesionalnih pozadina i iskustava znanstvenika koji se bave ovim područjem, a što doprinosi raznolikosti pogleda na agilnost.

Raznolikost u definicijama agilnosti vidljiva je u znanstvenoj literaturi. J. M. Sheppard i Young (2006) definiraju agilnost kao sposobnost brze promjene smjera kretanja uz minimalni gubitak brzine. Chelladurai, Yuhasz, i Sipura (1977) predlaže klasifikaciju agilnosti na jednostavnu, vremensku, prostornu i univerzalnu, gdje svaka kategorija uključuje različite razine neizvjesnosti u vremenu i prostoru. Warren Young, Dos' Santos, Harper, Jefferys, i Talpey (2022) definiraju agilnost kao brzinu promjene smjera uz perceptivne i komponente donošenja odluka. Nadalje, autori poput Moreno (1995), koriste termin "quickness" kao komponentu agilnosti, što komplicira dogovor o univerzalnoj defniciji agilnosti (J. M. Sheppard i Young, 2006). Sekulić, Pehar, i sur. (2017) ističu da agilnost uključuje pred-planirane promjene smjera (CODS) i reakciju na nepredviđene vizualne ili zvučne podražaje, naglašavajući važnost perceptivno-kognitivnih komponenti.

Različite definicije agilnosti odražavaju kompleksnost ove motoričke sposobnosti te širi kontekst u kojem se pojam agilnost koristi. Na primjer, u sportovima gdje su brze promjene smjera i reakcije na podražaje ključne, agilnost se često definira s naglaskom na kognitivne komponente, poput donošenja odluka i vizualnog skeniranja (Scanlan, Humphries, Tucker, i Dalbo, 2014). Nasuprot tome, definicije koje dolaze iz literature koja se odnosi na trening mladih sportaša više naglašavaju motoričke sposobnosti, poput brzine i eksplozivnosti (Trecroci i sur., 2016). Ova raznolikost u definicijama može biti posljedica različitih ciljeva istraživanja i specifičnosti sportskih disciplina, što dodatno otežava dogovor o univerzalnoj definiciji agilnosti. S obzirom na ove različite pristupe, jasno je da je agilnost od vitalne važnosti za sportsku izvedbu te da postoji distinkcija u definicijama koje uključuju kognitivne sposobnosti i one koje ih ne spominju.

1.2 Reaktivna i pred-planirana agilnost

Razlikujemo dvije glavne komponente agilnosti; reaktivnu i pred-planiranu agilnost (CODS - Change of Direction Speed). Reaktivna agilnost podrazumijeva sposobnost brzog reagiranja na vanjski podražaj, dok se CODS odnosi na sposobnost promjene smjera kretanja u unaprijed planiranim uvjetima bez vanjskog podražaja (Sekulić, Pehar, i sur., 2017). Reaktivna agilnost zahtijeva visoku razinu perceptivnih i kognitivnih vještina, uključujući procesuiranje vizualnih ili zvučnih informacija te brzo donošenje odluka o smjeru kretanja. Ovo je posebno važno u sportovima gdje su igrači često suočeni s neočekivanim pokretima protivnika ili promjenama situacije na terenu (W. B. Young i Willey, 2010). S druge strane, CODS uključuje unaprijed određene pokrete gdje sportaš ne mora reagirati na vanjski podražaj, već izvodi slijed pokreta prema unaprijed planiranom obrascu kretanja (Paul i sur., 2016).   s velikim brojem motoričkih faktora kao što su brzina, jakost, snaga i koordinacija, koji zajedno doprinose učinkovitosti agilnih pokreta. Fiziološki, agilnost zahtijeva mišićnu jakost i snagu, što uključuje sposobnost mišića da brzo generiraju silu (M. Hammami, Negra, Shephard, i Chelly, 2017). Također, neuromuskularna koordinacija igra ključnu ulogu jer omogućuje skladno djelovanje različitih mišićnih grupa (W. B. Young, McDowell, i Scarlett, 2001). Nadalje, biomehanički čimbenici uključuju mehaniku tijela tijekom agilnih pokreta i utjecaj agilnosti na koštani sustav. Pri agilnim pokretima, tijelo mora održavati ravnotežu dok se brzo kreće u različitim smjerovima. Takvi pokreti mogu značajno opteretiti zglobove i kosti, što zahtijeva dobru biomehaničku učinkovitost kako bi se smanjio rizik od ozljeda (W. B. Young i sur., 2001).

Različite motoričke sposobnosti utječu na višestranu prirodu agilnosti. Najbolje se to vidi kroz utjecaj na agilnost koji imaju brzina, snaga, ravnoteža i koordinacija. Brzina je sposobnost brzog kretanja po terenu ili promjene položaja tijela što je čini iznimno važnom za agilnost jer omogućuje sportašu da brzo reagira i prilagodi se situacijama u igri (Gabbett, Kelly, i Sheppard, 2008). Snaga je sposobnost generiranja maksimalne sile u kratkom vremenskom razdoblju te je izrazito bitna za brze promjene smjera kretanja (M. Hammami i sur., 2017). Ravnoteža je sposobnost održavanja težišta tijela iznad oslonca te je neophodna za izvođenje brzih promjena smjera bez gubitka stabilnosti (Sporiš, Jukić, Milanović, i Vucetić, 2010). Koordinacija je skladno funkcioniranje dijelova tijela pri izvođenju složenih pokreta koje osigurava da su pokreti uglađeni i učinkoviti, smanjujući rizik od ozljeda i poboljšavajući izvedbu (W. B. Young i sur., 2001). Brzo vrijeme reakcije, vrijeme između izlaganja podražaju i početka odgovora pokretom od vitalne je važnosti za agilnost jer omogućuje sportašu da brzo reagira na dinamična i nepredvidiva okruženja (Zemková i Hamar, 2014).

1.3 Agilnost kod djece

Agilnost igra važnu ulogu u fizičkom razvoju djece i mladih sportaša. Kako djeca rastu i razvijaju se, tako se njihova mišićna masa i snaga povećavaju a samim time poboljšava se i sposobnost izvođenja agilnih pokreta. Rommers i sur. (2019) naglasili su da rast i sazrijevanje značajno utječu na agilnost i brzinu kod mladih sportaša. Poznavanje i razumijevanje razvojnih faza važno je za prilagodbu treninga kako bi odabrane vježbe bile u skladu s trenutnim tjelesnim sposobnostima u tom trenutku rasta i razvoja. Fransen i sur. (2017) ističu kako trening agilnosti može značajno doprinijeti fizičkom razvoju, poboljšavajući koordinaciju, snagu i ukupnu tjelesnu kondiciju. Iz navedenog može se zaključiti da nema razloga da se trening agilnosti ne uvede u školske i sportske programe jer može donijeti brojne prednosti. Agilnost se može integrirati u satove tjelesne i zdravstvene kulture (TZK) kako bi se poboljšala ukupna kondicija učenika te omogućila profesorima TZK selekcija, upućivanje i preporuka učenicima za bavljenje određenim sportom.

Odnos između agilnosti i puberteta opsežno je analiziran kroz različite faze sazrijevanja, posebno u kontekstu sportskih sposobnosti. Sazrijevanje značajno utječe na agilnost i fizičke sposobnosti kod mladih, što pokazuju brojna istraživanja fokusirana na elitne mlade nogometaše i druge mlade sportaše. Asadi, Arazi, Ramirez-Campillo, Moran, i Izquierdo (2017) proveli su i meta-analizu koja je pokazala da pliometrijski trening poboljšava sposobnost promjene smjera (COD) kod mladih ispitanika, pri čemu su stariji ispitanici pokazali veća poboljšanja u usporedbi s mlađima. Rommers i sur. (2019) istraživali su koordinaciju, brzinu i agilnost kod elitnih mladih nogometaša i otkrili značajne razlike vezane uz dob i zrelost. Igrači koji ranije sazrijevaju nadmašili su svoje vršnjake koji kasnije sazrijevaju u testovima brzine i agilnosti na razinama U14 i U15. Studija je istaknula važnost uzimanja u obzir statusa zrelosti pri identifikaciji talenata i treniranju, budući da su fizičke performanse značajno pod utjecajem vremena sazrijevanja tijekom puberteta. Ostojić i sur. (2014) proveli su longitudinalnu analizu 14-godišnjih srpskih nogometaša, pokazujući da djeca koja kasnije sazrijevaju imaju veće šanse za postizanje elitne nogometne vještine u usporedbi s onima koja ranije sazrijevaju. Ova studija naglašava da djeca koja ranije sazrijevaju imaju fizičku prednost tijekom mladosti, ali ne održavaju nužno tu prednost u odrasloj dobi. Trecroci i sur. (2016) istražili su učinke treninga brzine, agilnosti i okretnosti (SAQ) na predadolescentne nogometaše i otkrili da takav trening značajno poboljšava ubrzanje i reaktivnu agilnost, dok je manje učinkovit za brzinu promjene smjera kretanja (CODS). Rezultati ukazuju da organizirani SAQ treninzi mogu poboljšati određene aspekte agilnosti u djetinjstvu, naglašavajući važnost metoda treninga specifičnih za dob (Trecroci i sur., 2016).

Ovakvi rezultati naglašavaju ključnu ulogu sazrijevanja u razvoju agilnosti i povezanih fizičkih atributa tijekom puberteta. Oni naglašavaju potrebu za dobno prikladnim treninzima i evaluacijom u mlađim kategorijama kako bi se osigurao optimalan razvoj i identifikacija talenata.

1.4 Prediktori agilnosti

Prediktori agilnosti uključuju niz faktora, kao što su genetske predispozicije, motoričke sposobnosti, morfološke karakteristike, neuromuskularna učinkovitost, kognitivne sposobnosti i trenažna dob. Genetske predispozicije mogu utjecati na sposobnost pojedinca za brze i koordinirane pokrete (Noohi i sur., 2016). Istraživanja pokazuju da su motoričke sposobnosti, poput visoke razine snage nogu i eksplozivne snage, ključni faktori za efikasnu agilnost (Sekulić, Spasić, Mirkov, Čavar, i Sattler, 2013). Morfološke karakteristike poput visine, mase i sastava tijela također igraju važnu ulogu u agilnosti (Ostojic i sur., 2014). Neuromuskularna učinkovitost odnosi se na sposobnost živčanog i mišićnog sustava da učinkovito surađuju, dok kognitivne sposobnosti uključuju brzinu donošenja odluka i vrijeme reakcije (Zemková i Hamar, 2014). Trenažna dob i iskustvo u specifičnim sportovima također mogu značajno utjecati na agilnost (W. B. Young i sur., 2001). Kod djece, agilnost se razvija kroz igru i strukturirane tjelesne aktivnosti koje uključuju brzinu i promjenu smjera. Kod mladih sportaša, agilnost je povezana s razvojem osnovnih motoričkih vještina te je ključna za uspješno sudjelovanje u timskim sportovima kao što su nogomet, rukomet i košarka (Lloyd i sur., 2015).

1.5 Prediktori agilnosti kod djece

Kao što je navedeno u prethodnom tekstu, agilnost je uvjetovana raznim faktorima koji utječu na njenu izvedbu. Kao i kod odrasle populacije i u populaciji djece zabilježeni su prediktori kojima se s većom ili manjom preciznošću može predvidjeti potencijal djeteta u agilnoj izvedbi. Istraživanja o prediktorima agilnosti kod djece uglavnom su se temeljila na sportskoj populaciji i detektiranju prediktora generičke pred-planirane agilnosti. Tako su França i sur. (2024) utvrdili da su jakost i snaga donjih ekstremiteta značajni prediktori pred-planirane agilnosti kod nogometaša adolescenta dobi 14,0 do 17,8 godina. Do sličnih rezultata došli su (Čaušević, Čović, i sur., 2023) ali na populaciji mladih košarkaša (13,41 – 15,64 godina). Utvrdili su kako je eksplozivnost mjerena CMJ i DJ testom najznačajniji prediktor pred-planirane agilnosti. Također, a slično kao u prethodno navedenom istraživanju na mladim nogometašima, specifičan sastav tijela s povećanim postotkom tjelesne masti determiniran je kao prediktor koji negativno utječe na izvedbu pred-planirane agilnosti (Čaušević, Rani, i sur., 2023). Studija koja se bavila neselekcioniranim uzorkom djevojčica u ranom pubertetu, potvrdila je neka od prethodno navedenih saznanja. Naime, Spasić, Uljević, Coh, Dželalija, i Sekulić (2013) ukazuju kako su sastav tijela i antropometrija slabi do srednje jaki prediktori agilnosti u ovoj populaciji. Utvrdili su i kako je od svih testiranih motoričkih varijabli reaktivna snaga najvažniji prediktor pred-planirane agilne izvedbe. Nadalje, Sekulić, Spasić, i Esco (2014) istražuju utjecaj ravnoteže, snage, reaktivne snage i morfologije na 5 različitih testova pred-planirane agilnosti kod dječaka pubertetske dobi. Zaključuju kako je reaktivna snaga najvažniji prediktor uspješnosti u testovima pred-planirane agilnosti (Sekulic i sur., 2014). Fatih (2009) istražuje povezanost između skočnosti i pred-planirane agilnosti, mjerene Heksagon testom kod djece pubertetske dobi. Utvrđuje značajne inverzne korelacije između ove dvije sposobnosti te zaključuje kako je snaga donjih ekstremiteta značajan prediktor uspješnosti izvedbe na testu nereaktvine agilnosti u toj dobi. Pregled dostupne literature pokazuje da kod djece pubertetske dobi na pred-planiranu agilnost najviše utječu sastav tijela te pojedini faktori snage i brzine (García Cantó i sur., 2015; R. Hammami i sur., 2018; M. Jones i Lorenzo, 2013; Sellami, Makni, Moalla, Tarwneh, i Elloumi, 2024).

Kada su u pitanju prediktori reaktivne agilnosti, važno je napomenuti da postoji znatno manje studija u odnosu na studije rađene na pred-planiranoj agilnosti, a istraživači se u njima fokusiraju na prediktore koji opisuju motorički i morfološki status ispitanika. Tako npr. Đolo, Milić, Nešić, i Grgantov (2022) utvrđuju trivijalne relacije između reaktivne agilnosti i skupa motoričko-morfoloških testova koji su procjenjivali brzinu, neplaniranu agilnost, izdržljivost i sastav tijela kod odbojkašica pubertetske dobi. Slične rezultate dobili su Horićka i Simonek (2021) na uzorku mladih nogometaša od U11 do U16 kategorije. Zbog vrlo malih uzročno-posljedičnih relacija između Illinois agility i Fitro agility check testa, zaključuju kako se radi o posve različitim dimenzijama agilnosti te da ih treba promatrati i trenirati u sport-specifičnom kontekstu (Horička i Simonek, 2021).

Pregledom literature uočljiv je nedostatak studija koje su se bavile kognitivnim kapacitetima kao mogućim prediktorima reaktivne agilnosti kod djece. Popowczak, Domaradzki, Rokita, Zwierko, i Zwierko (2020) autori su jedne od rijetkih studija koja se bavila prediktorima reaktivne agilnosti kod mladih sportaša. Testirano je 149 dječaka i 157 djevojčica u dobi između 13 i 15 godina koji su se bavili košarkom, rukometom i odbojkom. Multipla regresijskom analizom utvrđeno je kako periferna percepcija značajno utječe na izvedbu reaktivne agilnosti kod dječaka ali ne i kod djevojčica bez obzira kojim se sportom bave (Popowczak i sur., 2020). U skupini adolescenata u dobi od 17 do 18 godina Horička, Šimonek, i Paška (2020) utvrdili su značajnu povezanost između reaktivne agilnosti i inteligencije (r=0,66), dok između kognitivnih sposobnosti i reaktivne agilnosti ta povezanost nije utvrđena (r=-0,12).

1.6 Dijagnostički postupci za procjenu agilnosti

Procjena stanja agilnosti bilo koje populacije ili pojedinca provodi se kako bi se predvidio njihov potencijal, identificirale slabe i jake strane, redovito pratio napredak, uspoređivale s normativnim vrijednostima ili postavili ciljevi plana i programa treninga (P. A. Jones, Bampouras, i Marrin, 2009; P. A. Jones, Thomas, Dos' Santos, McMahon, i Graham-Smith, 2017). S obzirom da agilnost generalno možemo podijeliti na reaktivnu i pred-planiranu, testove također možemo razvrstati u te dvije glavne kategorije (Nimphius, Callaghan, Bezodis, i Lockie, 2018). Unutar svake od njih postoji skupina testova koji mjere baziČnu (generičku) agilnost i skupina testova usmjerenih na dijagnosticiranje sport-specifične agilnosti, pri čemu se testovi izvode s rekvizitima i obrascima kretanja karakterističnima za određeni sport (Warren Young i Farrow, 2013). Važno je znati situacije u kojima se sportaši/ispitanici nalaze i koji tip agilnosti u njima dominira kako bi odredili ispravnu proceduru mjerenja. Ako su agilne aktivnosti prethodno planirane, odabiru se testovi koji mjere pred-planiranu dimenziju agilnosti. Suprotno, ukoliko se u tipičnim situacijama promjena smjera kretanja izvodi nakon nekog vanjskog podražaja, valja koristiti testove konstruirane za procjenu reaktivne agilnosti (Dawes, 2019). Osim poznavanja strukture kretanja, prilikom odabira testova važno je izabrati i testove koji imaju dobre metrijske karakteristike te su prethodno validirani na metodološki primjeren način. To znači da odabrani testovi moraju zadovoljavati visoku pouzdanost, homogenost, osjetljivost i valjanost. Pouzdanost testa agilnosti očituje se točnošću mjerenja i konzistentnim rezultatima u ponovljenim mjerenjima, homogenost u zavisnosti rezultata o razini agilnosti pojedinog ispitanika, te osjetljivost u uspješnom razlikovanju ispitanika prema razini agilnosti, dok se valjanost očituje procjenom mjeri li test uopće agilnost (Dizdar, 2006; Sekulić, Pehar, i sur., 2017; Spasić, Krolo, Zenić, Delextrat, i Sekulić, 2015). Dosadašnja istraživanja u području metrijskih karakteristika i konstrukcije testova agilnosti upućuju na dva osnovna problema: 1) kako u mjerenju pred-planirane agilnosti izolirati agilnost od brzine kretanja (pritom valja napomenuti kako brzina reakcije, usporavanja i ubrzavanja nisu problem) te 2) kako testirati reaktivnu agilnost? Prvi problem je povezan s testovima u kojima se promjena smjera izvodi nakon (pre)dugih kretanja, što rezultira time da je rezultat na testu znatno više povezan uz brzinu kretanja ispitanika, a manje uz njegovu sposobnost da brzo i učinkovito ubrzava, usporava i/ili mijenja smjer kretanja. Primjer takvog testa je često korišteni Illinois test, u kojem se smjer kretanja mijenja tek nakon 9,15 m brzog trčanja, a koje se u jednom izvođenju testa provodi čak četiri puta (Raya i sur., 2013; J. M. Sheppard i Young, 2006). S druge strane, iako je opisan veliki broj raznolikih testova pred-planirane agilnosti, kod njih ne postoji vanjski stimulans na koji ispitanik treba reagirati, pa u njima izostaje procjena kognitivnih i reaktivnih kapaciteta ispitanika. Zbog toga su ovi testovi jednostavniji za konstrukciju i provedbu (W Young, Hawken, i McDonald, 1996; WB Young, James, i Montgomery, 2002). Osim toga, testiranje reaktivne agilnosti prije svega je tehnološki uvjetovano, jer zahtijeva mjerne uređaje koji će kreirati vizualni ili akustični podražaj, te precizno izmjeriti ispitanikovu reakciju na isti i brzinu potrebnu za promjenu smjera kretanja nakon podražaja. Obzirom na spomenuto, jasno je kako su testovi za procjenu reaktivne agilnosti pratili tehnološki napredak i, shodno tome, značajno se razvijali u posljednjih 20-ak godina. U zadnje vrijeme razvijeni su protokoli za testiranje reaktivne agilnosti u rukometu, futsalu, nogometu, košarci i tenisu (Krolo i sur., 2020; Pokrajčić, Marić, Foretić, i Uljević, 2021; Sekulić i sur., 2019; Sekulić, Pehar, i sur., 2017; Sekulić, Uljević, Perić, Spasić, i Kondrić, 2017a; Sinković, Foretić, i Novak, 2022; Sisić, Jeličić, Pehar, Spasić, i Sekulić, 2015). Većina ovih testova pokazuje visoku razinu pouzdanosti, s ICC vrijednostima koje se kreću od 0,72 do 0,90. Na tržištu se pojavljuju uređaji koji omogućavaju visoku pouzdanost i općenito dobre metrijske karakteristike testova, a koje je moguće koristiti i za trening i za testiranje, te posjeduju mogućnost prilagodbe i kreiranja testova, kao i jednostavnu kontrolu putem aplikacija dostupnih na pametnim telefonima (Myers, Toonstra, i Cripps, 2022; Pavlinović, 2022; Willberg, Kohler, i Zentgraf, 2023). Sve navedeno poboljšava mogućnost terenskog testiranja reaktivne agilnosti u svakodnevnoj praksi.

1.7 Ciljevi istraživanja

Ova doktorska disertacija usmjerena je na provođenje istraživanja u populaciji gdje nedostaje testiranja i podataka, posebno kod djece u predpubertetu i ranom pubertetu. Prvi cilj bio je utvrditi mogu li neke motoričke sposobnosti, kao i nekoliko antropometrijskih mjera, poslužiti kao prediktori pred-planirane agilnosti. Druga studija imala je za cilj konstruirati i validirati novorazvijeni test agilnosti za procjenu reaktivne agilnosti kod školske djece. Kao što je navedeno u uvodnom tekstu, reaktivna agilnost zahtijeva procesuiranje vizualnih ili zvučnih informacija te brzo donošenje odluka o smjeru kretanja. Obzirom da je reaktivna agilnost bliža sportskim igrama, gdje su igrači suočeni s neočekivanim pokretima protivnika, posebna pažnja posvećena je konstruiranju novog testa za procjenu reaktivne i pred-planirane agilnosti, koji će se koristiti za testiranje osnovnoškolaca. Glavni cilj treće studije bio je utvrditi povezanost između antropometrijskih mjera, motoričkih sposobnosti i reaktivne agilnosti kod dječaka i djevojčica u ranom pubertetu. U četvrtoj studiji cilj istraživanja bio je istražiti povezanost između kognitivnih kapaciteta, mjerenih Stroop testom, i procjene reaktivne agilnosti (RAG) kod dječaka i djevojčica u pubertetu. Pregledom literature različiti autori, kao Paul i sur. (2016), sugeriraju da buduća istraživanja trebaju nadmašiti trenutne 'Y-oblik' dizajne testova i razviti alternativne pristupe koji obuhvaćaju složenost sportskih specifičnih scenarija agilnosti, uključujući višestruke mogućnosti reakcije i različite tipove podražaja. Naglašavaju potrebu za pouzdanim testovima koji uključuju korištenje sportske opreme i različitih pokreta kako bi se bolje razumjele kognitivne kvalitete i sposobnosti donošenja odluka sportaša. Sekulić, Uljević, Perić, Spasić, i Kondrić (2017) preporučuju razvoj protokola testiranja koji uključuju višestruke mogućnosti reakcije i druge vrste podražaja, uz potrebu ispitivanja primjenjivosti ovih testova na mlađe dobne skupine. Popowczak i sur. (2020) predlažu istraživanje utjecaja periferne percepcije i kognitivnih sposobnosti na agilnost, s obzirom na to da je njihova studija pronašla značajne veze između tih faktora i agilnosti kod mladih sportaša. U ovoj disertaciji predstavljen je rad koji istražuje povezanost kognitivnih sposobnosti i reaktivne agilnosti. Sve prethodno navedene preporuke naglašavaju važnost razvijanja naprednijih i prilagodljivijih testova koji mogu bolje procijeniti različite aspekte agilnosti kod djece i mladih sportaša.

2. IZVORNE STUDIJE

2.1Differential Influence of General Anthropometric and Motor Predictors on Pre-planned Agilityin Pubescent Boys and Girls: A Multiple Regression Study

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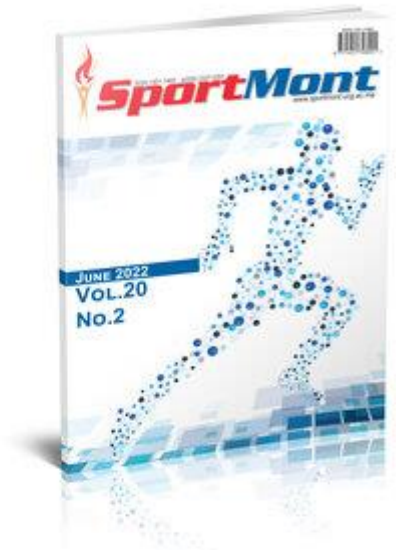

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ORIGINAL SCIENTIFIC PAPER

Differential Influence of General Anthropometric and Motor Predictors on Pre-planned Agility in Pubescent Boys and Girls: A Multiple Regression Study

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Abstract

In this study, we investigated the influence of balance, jumping power, and speed as well as morphological variables for three different agility tests in early pubescent boys (n=73) and girls (n=63). The predictors included body height and mass, body fat, high jumps, the overall stability index, ankle mobility, and a 10 and a 15 m sprint. The statistical analysis included calculations of correlations, regression models for the correlated variables, and the validation of the regression models. The calculated regression models for the male group explained 38% of the variance in a Zig-Zag test, 12% in a 20-yard test (20Y), and 81% in a T-test. The significant regression model for the Zig-Zag test included body mass, high jumps, and a 10 m sprint. The 20Y test had no predictors in the male group. For the T-test, the only predictor was the 10 m sprint. The calculated regression models for the female group explained 57% of the variance in the Zig-Zag test, 32% in the 20Y test, and 42% in the T-test. The significant regression model in the female group included only the 10 m sprint for all three agility criteria. The regression models were cross-validated using the second half of the sample (boys: n=36; girls: n=31). The correlation between the predicted and the achieved scores provided a statistically significant validation for all agility tests.

Keywords: morphology, change of direction, motor abilities, children, mobility

2.1.1 Introduction

Agility is defined as the ability to undertake a fast and effective change of movement direction and speed (Sekulic et al., 2013). It consists of an explosive movement start, acceleration, deceleration, a change of direction, and the restoration of fast movement whilst maintaining a dynamic balance (Sheppard & Young, 2006). Current research shows that agility has two different forms: pre-planned and non-planned (Young et al., 2015). Pre-planned agility does not include a response to external unpredictable stimuli whereas nonplanned does (Farrow et al., 2005). Both agility types occur inthe majority of sporting activities. In more complex activities such as team sport games, non-planned agility is of greater importance for a successful performance (Young & Willey,2010).

As in the adult athlete population, agility is significantly present in the physical activities of children. The majority of unstructured games and structured sports games of children abound with fast and reactive short runs, various jumps, and hops. The development of agility is influenced by biological maturation; certain phases of child development are more sensitive than others. According to Balyi & Hamilton (2004), the best age for developing agility is between the 9th and 12th year. In the study of Demirhan et al. (2017), the authors reported that agility develops rapidly until puberty and that three years after this period, agility performance decreases. After a period of rapid development, agility increases once more until maturity (Demirhan et al., 2017).

Due to its complexity, agility depends on motor abilities such as speed, power, coordination, or balance, but also on several anthropometric characteristics. However, a literature review shows inconsistent findings. In study of Little and Williams (2005), the authors concluded that acceleration, maximum speed, and agility were specific qualities that were relatively unrelated to one another. Similar findings were reported by Marković (2007), where the author found a poor relationship between strength and power qualities and agility performance. Conversely, Negra et al. (2017) concluded that agility performance, speed time, and jumping ability could represent the same motor abilities in competitive-level young male team sport athletes. Similarly, in the study of Barnes etal. (2007), the authors found that individuals with a greater countermovement performance also had quicker agility times, indicating that training predominantly in the vertical domain may also yield improvements in agility performance.

Following on from the above-mentioned studies, it is also important to identify the factors that influence agility performance in children. Such information could help strength and conditioning experts as well as physical education teachers to design training plans with greater efficiency for the agility development of children. Hence, the main goal of this research was to assess if speed, power, mobility, and balance as well as several anthropometric measures could be predictors of agility performance in early pubescent boys and girls. It was expected that the selected predictors would independently explain the variance in the agility criteria.

2.1.2 Methods

Participants

Boys (n=73) and girls (n=63) aged 12 to 13 years were recruited for this study from several schools in the same city. The average height was 170.93±8.47 for boys and 166.36±5.78 for girls (mean ± SD). The average body mass was 62.49±15.21 kg for boys and 56.23±9.90 kg for girls. The testing was performed as part of the initial screening at the beginning of their sportive seasons. All participants were in good health based on an initial medical screening. Two had suffered recent musculoskeletal disorders (i.e., injury and pain prevalence) and were not included in the investigation. The participants were required to answer a questionnaire that was designed to assess the type of sports in which they had previously engaged. If participants played in agility-saturated sports, they were not included in the study (n=17). Only the participants who were not previously involved in sports or those who were involved in sports where agility was not systematically trained (e.g., swimming, track and field, and rowing) were included in this investigation (n=71). The total sample of participants was randomly divided into validation (boys: n=36; girls: n=31) and cross-validation (boys: n=37; girls: n=32) subsamples. The Ethical Board of the University of Split, Faculty of Kinesiology, Split, Croatia, provided written approval to proceed with the investigation. The participants were informed of the purpose of the study and their parents provided written consent.

Measures and Procedures

The anthropometric variables that were analysed in this study were body height, body mass, and body fat. Additional tests included an explosive power test (high jump), a balance test measurement of the overall stability index, and a 10 and a15 m sprint test to measure running speed and ankle mobility. As different sports require different types of agility, three different agility tests were conducted: a T-shaped course test, a Zig-Zag test, and a 20Y shuttle test (Spasic et al., 2015; Sisicet al., 2015).

Body height and mass were assessed using a Seca Instruments stadiometer and a weighing scale (Hamburg, Germany). Body fat was measured using a Tanita BC-418segmental body composition analyser (Tanita Corp., Tokyo, Japan), which provides a print-out of the calculated body fat (Pietrobelli et al., 2004). The subjects stood with bare feet on the metal sole plates of the machine. Agility and running speed were measured using a Brower timing system (Salt Lake City, UT, USA). The high jump was measured using an Opto jump system, a dual-beam optical device that measures ground contact and flight time during a jump or series of jumps (Microgate, Bolzano, Italy; Schiltz et al., 2009). Balance was measured using a Biodex Balance System (Shirley, NY, USA).

For the T-shaped course test, 4 cones of 30 cm were arranged at the points of the required directional changes. When the test began, the participants were required to sprint forward along Course A (9.14 m) until they could touch the tip of the first cone with their right hand. They then side-shuffled leftward along Course B (4.75 m) until touching the tip of the second cone with their left hand. Next, they side-shuffled rightward along Course C (9.5 m) until touching the tip of the third cone with their right hand. They then side-shuffled leftward along Course D (4.75 m) until touching the tip of the fourth cone with their left hand. Finally, they back-pedalled over Course E (9.14 m) until reaching the finishing point (which was the original starting point). The trials were deemed unsuccessful if the participant failed to touch a designated cone, crossed their legs whilst shuffling, or failed to face forward at all times.

The Zig-Zag agility test consisted of maximal running throughout a 4×5 m zig-zag course. The timing began ona sound signal and stopped when the participant passed through a timing gate.

For the 20Y shuttle test, the examinee started with a three pointstance and ran along Course A (5 yd, 4.57 m), Course B (10 yd, 9.14 m), and finally along Course C (5 yd, 4.57 m).The countermovement jump test began with the participant standing in an upright position. A fast downward movement to approximately a 90° knee flexion was immediately followed by a quick upward vertical movement as high as possible, all in one sequence. The test was performed without an arm swing as the hands remained on the hips.

The overall stability index presents the average tilt in degrees from the centre of a platform. The higher the numerical value of the index, the greater the variability from the horizontal positioning; i.e., the greater the instability whilst balancing on the platform. The stability testing was performed without footwear. The participants established a foot position with a comfortable stance width that allowed them to maintain the most stable (horizontally levelled) position possible on the platform. The positioning of the feet was recorded and marked with tape using coordinates on the grid of the platform to ensure that the stance was consistent during the trials. The participants were required to maintain an upright posture whilst keeping the arms to the sides and looking straight ahead at the Biodex LCD monitor, which was approximately0.3 m away. One practice trial was allowed before the three test trials. Each testing trial lasted 20 s. The resistance level was set at number 9 on a scale with anchors of 1 (least stable) and 12 (most stable).

For the 10 m sprint, the start-line position was placed 1m before the first timing gate. The timing was only triggered when the infrared beams were disrupted. A second electronic timing gate was positioned 11 m from the start line. The participants were instructed to begin with their preferred foot forward placed on a line marked on the floor and to run as quickly as possible along the 11 m distance. The times were recorded in hundredths of seconds. The same procedure was conducted for the 15 m sprint, with timing gates positioned 1and 16 m from the start line (Duthie et al., 2006).

All of the tests were performed indoors on a wooden gymnasium floor. Before testing, the participants completed a 15min warm-up, which included jogging, lateral displacement drills, dynamic stretching, and light jumping. The sequence of testing was the same for all the participants. The first day of data collection consisted of an anthropometric assessment and power and speed measurements. During the second day, the participants performed the balance test and the three agility tests. During the course of the testing, the participants were asked to maintain their normal diet. To account for a diurnal variation in fitness abilities, all of the tests were performed at the same time of the day (9 to 11 a.m.) from April to June. Before the data collection began, the participants were familiarized with the testing procedures and allowed one practice trial of each test at a slow tempo. The participants performed three trials of each test with 3–4 min rest between the trials except for the balance tests, where 1 min of rest was allowed between the trials. In the case of evident fatigue, a longer rest period was allowed. The participants performed the tests wearing their choice of running shoes (excluding the balance testing, which was completed with bare feet). For tests automatically measured by the Brower timing system, Optojump, and the Biodex balance system, the same examiner assessed all participants.

Statistical Analyses

The statistical analyses included the calculation of the descriptive statistical parameters (means and standard deviations) and the calculation of the Pearson correlation to assesst he associations between the variables. The results of the correlation analysis determined the pick of the variables for the multiple regression analysis; only significantly correlated variables were included. All other variables were excluded from the regression analysis. The predictors that were included in the regression analysis were the body height, vertical jump, and 10 m sprint. The successful regression models were then applied to the cross-validation group. The regressions were cross-validated by Bland–Altman plots of the average between the calculated and the achieved scores (abscise) and the differences between the achieved and the calculated scores (ordinate).For all the analyses, Statistica 14.0 (TIBCO Software Inc, USA) was used, and a p-level of 95% was applied.

2.1.3 Results

Significant linear correlations were found between the vertical jump height (VJH) and the 10 m sprint (S10m) as motor predictors and agility criteria (Table 2).

Table 1. Descriptive statistic results

Variables	M	F
	Mean ± SD	Mean ± SD
BH	170.93 ± 8.47	166.36 ± 5.78
BM	62.49 ± 15.21	56.23 ± 9.90
BFat	20.63 ± 8.20	24.24 ± 7.32
VJH	26.16 ± 7.22	22.09 ± 4.17
S10m	1.42 ± 0.59	1.70 ± 0.34
S15m	2.42 ± 1.00	2.91 ± 0.57
LOS	34.57 ± 10.33	35.52 ± 11.36
TTest	12.15 ± 1.21	12.65 ± 0.99
ZigZag	6.37 ± 0.55	7.02 ± 0.56
20Y	5.87 ± 0.53	6.30 ± 0.47
ADD	33.84 ± 14.63	38.97 ± 7.79
ABD	36.52 ± 15.91	42.10 ± 8.36
DFlex	21.70 ± 10.16	27.41 ± 7.43
PFlex	36.38 ± 15.67	44.03 ± 8.52

Legend: BH - body height; BM - body mass; BFat - body fatt; VJH - vertical jump height; S10m - sprint 10m; S15m - sprint 15m; LOS - balance test; TTest - T course agility test; ZigZag - zig zag agility test; 20Y - 20 yards agility shuttle test; ADD - ankle adduction; ABD - ankle abduction; DFlex - dorsiflexion; PFlex - plantarflexion

Body mass (BM) and body fat (BFat) as morphological predictors also showed significant correlations with the agility tests. Body height showed no significant correlations with the agility criteria in both groups. The balance test (LOS) only correlated with the 20Y agility test in the male group. The ankle mobility tests showed no correlations with the agility criteria in the male group, but ankle adduction (ADD) and ankle abduction (ABD) showed significant correlations with the Zig- Zag agility test in the female group (Table 2). The calculated regression models for the male group explained 38% of the va-

Table 2. Pearson correlation between studied variables

Predictors	M			F		
	Zig-Zag	20Y	T-test	Zig-Zag	20Y	T-test
BH	0.17	-0.07	-0.01	0.10	-0.02	0.00
BM	0.37*	0.21	0.28*	0.38*	0.27*	0.40*
BFat	0.28*	0.27*	0.33*	0.31*	0.51*	0.51*
VJH	-0.37*	-0.51*	-0.47*	-0.33*	-0.47*	-0.47*
S10m	0.55*	0.79*	0.81*	0.40*	0.54*	0.37*
LOS	-0.21	-0.26*	-0.25	0.01	-0.15	-0.10
ADD	0.02	-0.10	-0.08	0.27*	0.04	0.08
ABD	0.08	-0.01	-0.06	0.27*	-0.07	-0.06
DFlex	0.02	-0.16	-0.15	0.26	0.05	0.04
PFlex	0.05	0.03	-0.00	-0.01	-0.13	-0.15

Legend: BH - body height; BM - body mass; BFat - body fatt; VJH - vertical jump height; S10m - sprint 10m; S15m - sprint 15m; LOS - balance test; TTest - T course agility test; ZigZag - zig zag agility test; 20Y - 20 yards agility shuttle test; ADD - ankle adduction; ABD - ankle abduction; DFlex - dorsiflexion; PFlex - plantarflexion

-riance in the Zig-Zag test, 12% in the 20Ytest, and 81% in the T-test (Table 3). The significant regression model for the Zig-Zag test included the body mass (BM), high jump (VJH), and 10 m sprint (S10m). The 20Y test had no predictors in the male group. For the T-test, the only predictor was the 10 m sprint (S10m).

Table 3. Regression summary for dependent variables for male participants

Predictor Zig-Zag	Beta	SE (beta)	b	SE (b)	t	p
Intercept			1.58	0.88	1.79	0.08
BH	0.32	0.12	0.02	0.01	2.64	0.01
VJH	0.38	0.10	0.08	0.02	3.74	0.00
S10m	0.32	0.11	0.84	0.29	2.89	0.01
R= .64; R2= .38; F=4.68; p=.00; SE=1.22						
Predictor 20Y	**Beta**	**SE (beta)**	**b**	**SE (b)**	**t**	**p**
Intercept			5.88	0.67	8.83	0.00
R= .34; R2= .12; F=2.35; p=.06; SE=.83						
Predictor T-test	**Beta**	**SE (beta)**	**b**	**SE (b)**	**t**	**p**
Intercept			5.88	0.67	8.83	0.00
S10m	0.92	0.06	7.30	0.47	15.42	0.00
R= .91; R2= .81; F=82.96; p=.00; SE=1.97						

Legend: BH - body height; VJH - vertical jump height; S10m - sprint 10m

The calculated regression models for the female group explained 57% of the variance in the Zig-Zag test, 32% in the20Y test, and 42% in the T-test (Table 4). The only significant regression model in the female group was the 10 m sprint(S10m) for all three agility criteria. The correlations between the obtained regression models

Table 4. Regression Summary for dependent variables for female participants

Predictor Zig-Zag	Beta	SE (beta)	b	SE (b)	t	p
Intercept			0.16	1.21	0.1	0.90
S10m	0.76	0.10	3.54	0.46	7.8	0.00
R= .78; R2= .57; F=15.02; p=.00; SE=1.04						
Predictor 20Y	**Beta**	**SE (beta)**	**b**	**SE (b)**	**t**	**p**
Intercept			2.23	1.11	2.00	0.05
S10m	0.43	0.11	1.52	0.40	3.79	0.00
R= .61; R2= .32; F=8.62; p=.00; SE=.98						
Predictor T-test	**Beta**	**SE (beta)**	**b**	**SE (b)**	**t**	**p**
Intercept			0.49	2.35	0.21	0.83
S10m	0.71	0.10	6.00	0.85	7.05	0.00
R= .71; R2= .47; F=15.20; p=.00; SE=2.08						

Legend: S10m - sprint 10m

and the achieved test results are shown in Tables 5 and 6. The regression models were confirmed because all the correlations were significant in both groups. In the male group, the highest correlation between the achieved and the predicted test results was noticed for the T-test (0.85) and the lowest was for the 20Ytest (0.44). Similar to the male group, in the female group, the highest correlation between the achieved and the predicted test results was noticed for the T-test (0.71) and the lowest was for the 20Y test (0.61). Bland–Altman plots were presented for all three agility tests.

Table 5. Comparisons between calculated and achieved scores for female and male students

Predictor	Female		r	Male		r
	Achieved	Predicted		Achieved	Predicted	
T-test	12.65±0.99	12.37±2.09	0.71*	12.15±1.21	10.55±4.28	0.85*
Zig-Zag	7.02±0.56	5.56±0.40	0.70*	6.37±0.55	5.82±0.95	0.82*
20Y	6.30±0.47	6.16±0.72	0.61*	5.87±0.53	5.54±0.28	0.44*

Legend: TTest - T course agility test; ZigZag - zig zag agility test; 20Y - 20 yards agility shuttle test

The plots showed that almost all cross-validation scores were positioned within the 95% CIs in the agility score differences (the observed minus the predicted scores). The biggest diversity was noticed in the Zig-Zag test for the female group.

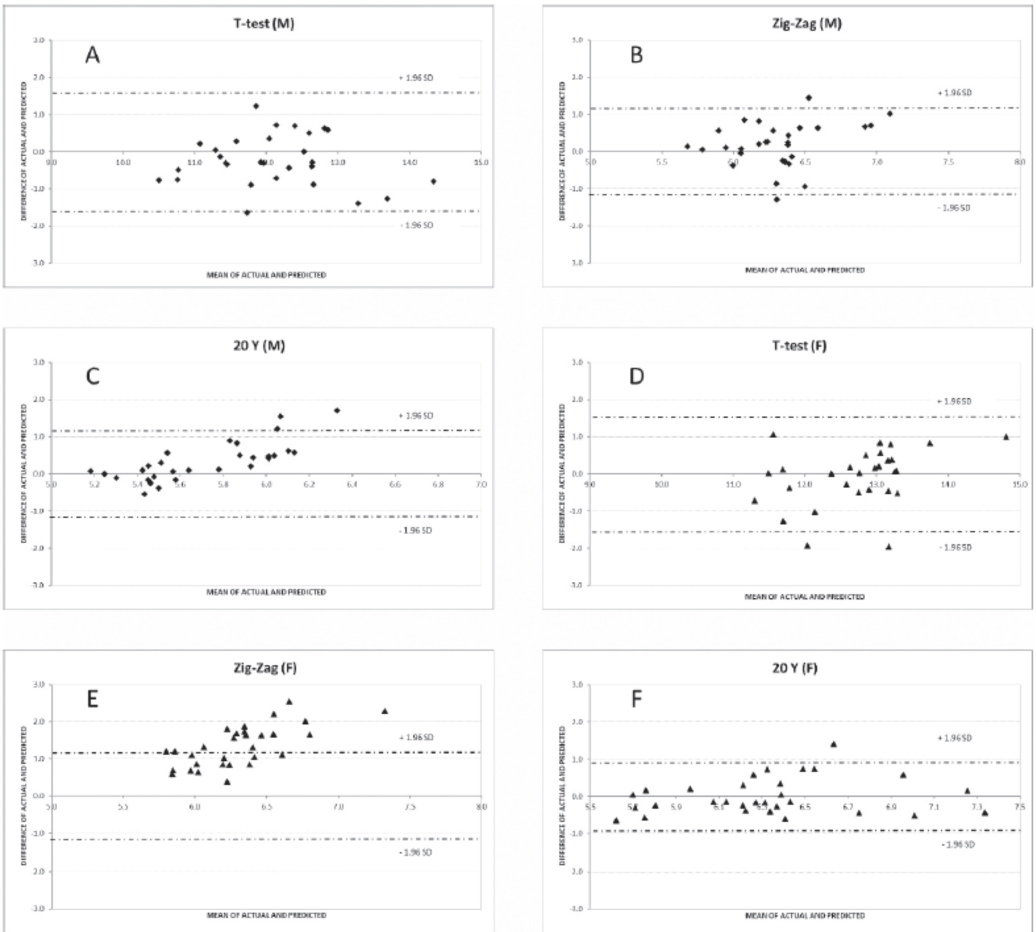

FIGURE 1. Bland-Altman plot for the calculated and achieved scores on the T-test. Zig-Zag and 20Y test for the cross-validation sample.

2.1.4 Discussion

This study had two major findings: (1) the 10 m sprint was found to be the most important predictor of agility performance; and (2) the body height and vertical jump were found to be predictors of the

Zig-Zag agility test in the male group. A literature review showed that BH can be an advantage as well as a disadvantage whilst performing agility tasks. According to Mathisen and Pettersen (2015), agility is significantly correlated with body height at the age of 13–14 years,but not in pre- and post-peak height velocity groups. Our cohort was in the stage of development where BH has the fastest growth and can disturb coordinative skills; thus, a negative influence on agility performance was expected (Philippaertset al., 2006). Nevertheless, we found no negative correlations with agility performance. The negative influence of body mass and body fat on agility is well-recorded in the literature, especially in agility-untrained cohorts such as ours (Dhapola &Verma, 2017).

Despite the importance of balance in agility movements, we found this only in one test in the male group (Sekulic etal., 2013; Acar & Eler, 2019; Cengizhan et al., 2019). The reasons for this could be found in the structure of the balance test used in our study. The LOS is a test that assesses dynamic balance in a stationary position. Conversely, in agility tests subjects have to maintain their balance through constant and fast movements. A lack of strong correlations between the specific measures of static and dynamic balance and agility was also reported by Sibenaller et al. (2010). Balance has a specific appearance during agility performance. This was proven in the study of Stirling, Eke & Cain (2018), where the authors reported that athletes with a higher agility score also had a higher balance score whilst undertaking an agility course and wearing inertial measurement units on their body. Hence, regression modelling should include more specific or surrogate agility balance tests. This was not the case in our study.

Girls had greater mobility in all ankle mobility tests. This could be connected to a lower muscle mass and muscle tone in girls compared with boys of an early puberty age (Roundet al., 1999). We speculated that the weaker muscles in girls produced a less stable ankle. As the ankle is one of the most engaged joints in agility movements, its instability or over-mobility can negatively influence agility performance. This was our prediction for the female group. This type of correlation was noticed in the Zig-Zag test for the female group.

As reported in the Results section, the 10 m sprint was the variable that predicted agility performance in almost all agility tests. However, other criteria oscillated among the regression models of the tests for the different genders. Specifically, the regression model for the Zig-Zag test in the boys included BH, VJH, and S10m whereas in the girls, the Zig-Zag agility was predicted only with S10m. As presented in the Bland–Altman plots, the predicted scores for the girls in the Zig-Zag test were poorer than the achieved scores (Figure 1). As the Zig-Zag test was complex and had many “stop-and-go” manoeuvres, cuts, changes of movement direction, accelerations, and decelerations, it was reasonable to expect that its prediction would be associated with other anthropological criteria (Sisic et al.,2015; Begu et al., 2018). This was not the case for the female group. Although we could only speculate why the regression model for the Zig-Zag test for the girls did not include other variables, it was clear that Zig-Zag agility performance was influenced by characteristics and abilities other than those studied (e.g., stride length, reactive speed, and leg and foot dimensions). Similarly, the regression model for 20Y in the male group did not exclude any predictor of agility performance. This finding should be considered taking into account the movement demands during the 20Y performance and the predictors used in this study. This was the only test that had a 180° turn and in which the eccentric strength of the lower extremities was extremely important during the deceleration phase (Hewit et al., 2011; Graham-Smith et al., 2018;). As no eccentric strength variables were used in this study, a lack of predictors for 20Y agility performance was expected. The findings from the T-test regression modelling were the opposite. Although the T-test had significant lateral movement demands (in total, 20 m of lateral movement) and a change of direction during the lateral movements, the only predictor in both groups was S10m, which was more characteristic of forward movement patterns. The T-test performance also consisted of 10 m forward running; the regression modelling did not incorporate any variables connected to lateral movements (such as leg length, lateral jump power, full-body coordination, and adduction and abduction muscle strength). Hence, S10m was our logical predictor of T-test agility performance in early puberty-age children.

2.1.5 Conclusion

The calculated linear correlations agreed with the findings of our research conducted on early puberty-age children. All three agility tests had valid regression models for both genders. From all the anthropological variables used in the regression modelling, speed was found to be the most important predictor of agility performance. Body measures, balance, power, and mobility tests used in the study were not reliable predictors of agility performance in early puberty. A major limitation of this study was the lack of inclusion of other abilities that could significantly contribute to a prediction model of agility performance in early pubescent boys and girls; e.g., cognitive qualities, coordination, reactive speed, and flexibility. In future studies, regression modelling should include more specific and/or surrogate tests that are similar to agility test movement demands. The results of this study indicate that agility is a complex ability. Accordingly, agility research, assessment, and training should be extensive in early puberty-age children.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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2.2Construction and Validation of Newly Developed Triangle Test of Reactive Agility in School Children

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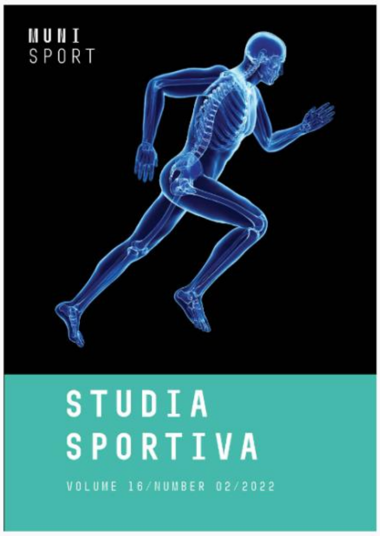

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Construction and Validation of Newly Developed Triangle Test of Reactive Agility in School Children

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Abstract

PURPOSE: Agility is described as a rapid whole-body movement with change of velocity or direction in response to the different stimuli. Scientific research identified two independent types of agility performances: pre-planned agility (CODS) and non-planned agility (RAG). CODS represent generic movement patterns. They can mimic the demands of a sport but all of the movements are pre-planned. In CODS there is no response to a stimulus like in RAG where movements are in response to cues such as the movements of the ball or actions of the opposition players. Literature review show lack of studies that assessed CODS and RAG in children, most probably due insufficiency in quality testing protocols. Hence, the purpose of this study was construction and validation of newly developed agility test that measures RAG performances in children. METHODS: For this purpose, the Blaze Pod system (BP) was used. Three lighting pods were mounted on three 50 cm cones in triangle formation with 4,5 meters distance between cones (TRGA). Results were collected via BP app. Four movement patterns were used to test RAG. Start and finish of the tests were conducted with the tap on BP pods. The sample comprised of 80 elementary school children (boys; n = 39, age = 14.88 ± 0.36 yrs, height = 174,3 ± 7,46 cm, mass 67,86 ± 16,78 kg, and girls; n = 41, age = 14.85 ± 0.31 yrs, height = 167.49 ± 5.72 cm, mass = 59.34 ± 10.54 kg). Statistical analysis included calculation of normality of distribution, reliability coefficients, correlations and analysis of variance. RESULTS: Tests showed acceptable reliability with CA = 0.58, ICC = 0.32 for boys and CA = 0.78, ICC = 0.55 for girls. Inter-item correlations were higher in girls' sample (r = 0.49–0.64) than in boys (r = 0.27–0.41). Also, test showed good sensitivity, normal data distribution and good homogeneity with no differences between items (boys; F = 0.07, p = 0.93; girls; F = 0.13, p = 0.88). Better reliability of TRAG test for girls is most probably caused by gender morphological differences. Namely, we observed greater standard deviations (SD) of height (BH) and mass (BM) in boys (boys; BH = 7.37, BM = 16.97; girls; BH = 5.68, BM = 9.7) and scientific research confirmed negative influence of BM and BH on reactive agility performance.

CONCLUSION: Altogether, newly constructed TRGA test seems to be reliable instrument for measuring reactive agility in pubescent boys and girls.

Keywords: non-planned agility, metric characteristics, pubescents, gender

2.2.1 Introduction

Agility can be described as ability to effectively change movement direction, accelerate and decelerate, without losing balance. According to Sheppard & Young (2006) agility is whole-body movement with change of velocity or direction in response to a stimulus (Sheppard & Young, 2006). It has been suggested that agility is a key condition for optimal performance in sports (Jeffreys,2006). According to literature, two types of agility has been defined; change of direction speed or pre-planned agility (CODS) and reactive, non-planned agility (RAG). CODS have been described as pre planned movements with no decision making, while on the contrary, RAG appear in response to a stimulus, commonly from opponent's action. Both of these agility types occur in majority of sport activities. In more complex activities, such as team sport games, RAG is more important for successful performance (Young & Willey, 2010).

During everyday play, children find themselves in situations which require change of speed and direction in response to some external stimuli. In their sport games or unstructured games, they have to regulate speed and movement direction and to anticipate the actions of others to avoid bumping into each other. In order to do so they have to develop motor skills but also perceptual skills essential for agility (Serpell, Ford, & Young, 2010). In a similar way, tests to assess agility should be constructed in a way to provide similar stimulus as during a game or sport.

The majority of previous literature show lack of studies that assessed RAG and has more closely examined CODS in children and adolescents who participate in/train different sports. In the study of Eler & Eler (2018) authors concluded that set of agility exercises conducted for 10 weeks has positive effect on COD speed performance (Eler & Eler, 2018). Furthermore, in the study of Acar &Eler (2019) authors have investigated effects of 8-week balance exercises on the speed and agility in10-12-year-old children in physical education lessons to have a positive effect on speed and CODS (Acar & Eler, 2019). Study made by Sekulic et al. (2014.) investigated the influence of balance, jumping power, reactive-strength, speed, and morphological variables on five different CODS performances in early pubescent boys (Sekulic, Spasic, & Esco, 2014). Authors have concluded that reactive strength was found to be the most important predictor of agility.

However, the lack of research of RAG in school children could be due to insufficiency in quality testing protocols. Furthermore, testing RAG for the mentioned population can be complicated, difficult and technologically demanding. The last one could be the reason why RAG testing started to appear in last few years. Also, most of the testing was done in sports clubs as a result of improving sport performance. As change of direction ability is considered primordial quality in many activities and important physical component related to youth health status (Sporis, Jukic, Milanovic, & Vucetic, 2010; Vicente-Rodríguez etal., 2011; Young, McDowell, & Scarlett, 2001). The purpose of this study was construction and validation of newly developed agility test that measures RAG performances in school children.

2.2.2 Methods

The study included 7th and 8th grade children (n = 80; boys; n = 39, age = 14.88 ± 0.36 yrs, height = 174,3 ± 7,46 cm, mass 67,86 ± 16,78 kg, and girls; n = 41, age = 14.85 ± 0.31 yrs, height = 167.49 ± 5.72 cm, mass = 59.34 ± 10.54 kg), all of them attending the same elementary school in Split, Croatia. Testing was performed during physical education classes. All participants were in a good health and none of them reported any current injuries specific to the ankle, knee or hip joints that might be expected to affect performance during the test. All parents of students gave their written informed consent before inclusion in the study. Informed consent was also obtained from the school principal.

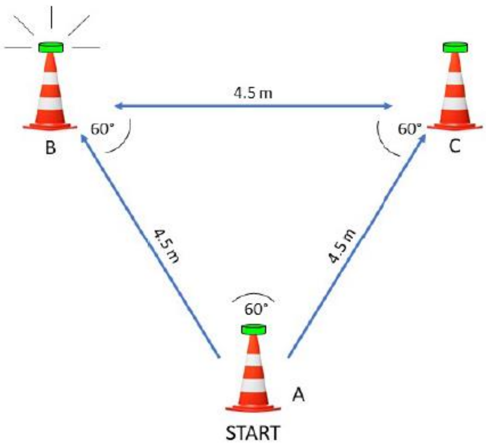
Subjects performed newly constructed “Triangle” RAG test (T RAG) at the beginning of their physical education (PE) class. The test was performed in the school gymnasium on the wooden floor and all PE classes were held in the morning shift. Before testing, the participants had completed a 5min warm-up which consisted of jogging, skipping, lateral running and light jumping. All students were familiarized with T RAG test procedure before data collection. Also, before T RAG test student made two running patterns of CODS test to additionally familiarize with Blaze Pod (BP) system which was used for the purpose of the study. Three lighting pods were mounted on three 50 cm cones in triangle formation with 4,5-meter distance between cones which is convenient distance for lighting pods to be in their visual perception field without looking down. The height of the cones forces the participants to be in athletic position which is suitable for fast change of direction. The participants were instructed to begin the test standing next to the starting cone, with their preferred foot forward. The foot of the front leg was placed laterally in relation to the cone. To start the T RAG, students would tap the first lighting pod (A), run to the next lighted cone, touch the designated pod, which triggers the last one. The testing was arranged in groups of 4-5 participants, which allowed for appropriate rest period between the tests. The rest interval was not was not less than 20 s between trials. For the TRAG test, participants did not know the scenario and were tested by the same four templates; (first trial: A–C–

B, second trial: A–B–A, third trial: A–C–A, fourth trial: A–B–C). Each participant conducted three random trials. Results were collected via BP application.

Statistical analysis included calculation of descriptive statistics, means and standard deviations for each “Triangle” attempts. The Kolmogorov – Smirnov (KS) test was used to check the normality of data distribution. Reliability of the newly developed test T RAG was calculated with correlation analysis, inter-item correlation and Crobmach’s alpha coefficients.

For all the analyses, Statistica 14.0 (TIBCO Software Inc., Palo Alto, CA, USA) was used.

Figure 1. T RAG test



2.2.3 Results

Results of descriptive statistics are shown in table. From KS test results can be noticed thatall variables have normal data distribution. As so, they are suitable for parametric statistical calculations. Results of distributions’ skewness and kurtosis refers on good test sensitivity since all its results fits in normal range except third item in male subjects (skew = 1.14; kurt = 3.34).

Table 1. Descriptive statistics

Variables	Mean	Min	Max	SD	Skew	Kurt	KS	p
T RAG 1 M	3.68	2.77	5.09	0.58	0.57	0.00	0.11	$p > .20$
T RAG 2 M	3.63	2.10	5.47	0.68	0.56	0.94	0.12	$p > .20$
T RAG 3 M	3.67	2.10	6.15	0.72	1.14	3.34	0.13	$p > .20$
T RAG 1 F	3.87	2.92	5.32	0.58	0.56	-0.09	0.11	$p > .20$
T RAG 2 F	3.88	2.77	6.20	0.62	1.01	3.69	0.10	$p > .20$
T RAG 3 F	3.86	3.22	5.05	0.43	0.63	0.28	0.09	$p > .20$

Legend: T RAG - “Triangle” RAG test, **M** – male student, **F** – female student, **1** – first attempt, **2** – second attempt, **3** – third attempt, **Mean** – arithmetic mean, **Min** – minimum, **Max** - maximum, **SD** – standard deviation, **Skew**– skewness, **Kurt** - kurtosis, **KS** – Kolmogorov-Smirnov test

Table 2. shows correlations between the items of measurement of newly constructed test for reactive agility in school children (T RAG). Significant correlations were found between all items of measurements in both samples. In male sample they ranged from 0.27 to 0.41, and in females ample from 0.49 to 0.64. Obviously, higher correlations are between items in female sample.

Table 2. Correlations between the items of newly constructed test

Variables	T RAG 1 M	T RAG 2 M	T RAG 3 M	Variables	T RAG 1 F	T RAG 2 F	T RAG 3 F
T RAG 1 M	1.00			T RAG 1 F	1.00		
T RAG 2 M	0.41 *	1.00		T RAG 2 F	0.64 *	1.00	
T RAG 3 M	0.27 *	0.29 *	1.00	T RAG 3 F	0.49 *	0.53 *	1.00

Legend: T RAG - "Triangle" RAG test, **M** – male student, **F** – female student, **1** – first attempt, **2** – second attempt, **3** – third attempt, * – significant correlation

Reliability coefficients (inter-item correlation and Crobmach's alpha) and results of analysis of variance between items of measurements are shown in table 3. Inter-item correlation coefficients (0.32-0.55) and Crobmach's alpha coefficients (0.58–0.78) show average to good reliability of newly constructed test for male and female respectively. When connected with results of correlations shown in table 2, and respecting sample size and specificity we may state that new test T RAG has good reliability and that has the ability of the scorer to produce the same result each time for the same T RAG test performance. Similarly, results of analysis of variance between items of measurements indicate that there are no significant differences between them in both samples. This means that results in different items don't depend on systemic errors. Generally, that test has good homogeneity and can be used as valid diagnostical tool for assessing reactive agility.

Table 3. Inter-item correlation, Crombach's alpha and analysis of variance

VARIJABLE	II r	Crombach's alpha (α)	F	p
T RAG M	0.32	0.58	0.07	0.93
T RAG F	0.55	0.78	0.13	0.88

Legend: T RAG M – Male "Triangle" RAG test, **T RAG F** – Female "Triangle" RAG test, **II r** – inter item reliability coefficient

2.2.4 Discussion

Results of the study indicate three important findings: (i) newly designed reactive agility tests has good sensitivity, (ii) newly designed reactive agility tests has average reliability, and (iii) newly designed reactive agility tests has good homogeneity.

Sensitivity

A sensitive protocol is one that is able to detect small, but important, changes in performance (Paul & Nassis, 2015). In our study, we observed consistent changes in performance between subjects in different items of measurement and therefore concluded that test has good sensitivity. Anyhow, bigger data dispersion was noticed in T RAG 3 M sample and in T RAG 2 F. Cause fort his could be searched in previous test that was used as familiarization protocol in which students had determined movement mode and which has been conducted as non-reactive test (T CODS).Most probably, because of its' similarity, this test confused some of the students and they were focused on "wrong" cone, late noticed mistake and consequently performed weaker in this item of measurement. Also, T RAG 2 F sample was conducted in the left side. We can assume that for majority of female students this was "weak side" and they reacted/performed slower than in other items of measurement. "Weak side" slower performance in agility tests was reported before in football, futsal, basketball and handball players, and we assume that this phenomena was present in our study also (Krolo et al., 2020; Pokrajčić, Marić, Foretić, & Uljević, 2021; Sekulic et al., 2019;Sekulic et al., 2017).

Reliability

The reliability of a test is an elementary prerequisite of the test's applicability because it directly indicates the error of measurement (Uljevic, Esco, & Sekulic, 2014). Significant correlation between the three T RAG movement patterns (II r) indicate good reliability of the T RAG test. Also, good value of Cronbach-alpha coefficients (α) for T RAG F and average value for T RAG M shows satisfactory reliability and reduced error of measurement. Reliability of newly constructed T RAG test is similar to reactive agility test in other studies (Krolo et al., 2020; Pojskic et al., 2018).But, like in before mentioned studies, T RAG test has lower reliability than it was reported in studies dealing with CODS tests (Dugdale, Sanders, & Hunter, 2020; Krolo et al., 2020; Serpell etal., 2010). Reactive agility tests are more complex and dependable on different physical features of the athletes (Sheppard & Young, 2006). Most of the time they demand sophisticated measurement tools, are consisted of short and fast movements that appear after cognitive and motor reaction/activity of the athlete. Unlike during CODS testing, every small mistake in test performance by athlete (e.g. inadequate sport shoes, slippery surface, etc.) or assessment by measurer (fuzzy test instruction, lousy control of measurement equipment, etc.) can significantly influence final result in performance. When having in mind that subjects in our study were elementary school students with very low exposure to agility stimuli lower reliability than in CODS testing protocols is not unexpected.

Homogeneity

Homogeneity is feature of test whish shows how results in all items of measurement are dependable on the same subject of measurement. T RAG test show good homogeneity since there wasn't noticed significant difference between items of measurements. Obviously, no systemic error, such as "learning effect" or subjects' fatigue, appeared during test performance. Hence, we conclude that T RAG test has good homogeneity and is valuable protocol for diagnosing reactive agility.

2.2.5 Conclusion

The purpose of this study was construction and validation of newly developed agility test that measures RAG performances in children. Tests showed acceptable reliability and therefore maybe used as appropriate test in evaluation of RAG in pubescent boys and girls. Also, test showed good sensitivity, normal data distribution and good homogeneity with no differences between items. Better reliability of constructed T RAG test for girls is most probably caused by gender morphological differences. Namely, we observed greater standard deviations of height and mass in boys and scientific research confirmed negative influence of BM and BH on reactive agility performance. In future research, it might be important to separate children which are involved in agility saturated sports and familiar with running technique than kids who are not, which could be considered as possible limitation of this study.

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2.3 Predictors of Reactive Agility in Early Puberty: A Multiple Regression Gender-Stratified Study

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Predictors of Reactive Agility in Early Puberty: A Multiple Regression Gender-Stratified Study

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Abstract

Reactive agility (RAG) is a crucial factor of success in sports, but there are practically no studies dealing with RAG among children. The main aim of this study was to identify predictors of RAG among early pubescent boys and girls. The participants were primary school boys (n = 73) and girls (n = 59) aged 11–12. The criterion variable was the originally developed “Triangle” test of reactive agility (Triangle-RAG). Predictors included anthropometric/body composition indices (body height, seated height, body mass, and body fat percentage) and motor abilities (10 and 20 m sprint, broad jump, squat jump, countermovement jump, drop jump, and two tests of change of direction speed—CODS (Triangle-CODS, and 20 yards)). The results of the univariate analysis showed that anthropometric/body composition indices were not significantly correlated to TRAG (0–4% of the common variance), while all motor abilities were significantly associated with TRAG (7–43% of the common variance) in both genders. Among boys, 64% of the TRAG variance was explained by multiple regression, with TCODS as the only significant predictor. Among girls, multiple regression explained 59% of the TRAG-variance with TCODS, countermovement jump, and drop jump as significant predictors. Differences in multivariate results between genders can be explained by (i) greater involvement in agility-saturated sports (i.e., basketball, tennis, soccer) in boys, and (ii) advanced maturity status in girls. The lack of association between anthropometric/body built and TRAG was influenced by the short duration of the TRAG (3.54 ± 0.4 s). Our findings suggest that pre-pubescent and early pubescent children should be systematically trained on basic motor abilities to achieve fundamentals for further developing RAG. Since in this study we observed predictors including only athletic abilities and anthropometric/body composition, in future studies, other motor abilities, as well as cognitive, perceptual, and decision-making parameters as potential predictors of RAG in children should be investigated.

Keywords: non-planned agility; pre-planned agility; anthropometry; children

2.3.1 Introduction

Agility is often defined as the ability to quickly and efficiently change the speed and direction of movement [1,2]. It belongs to the domain of speed-explosives abilities that are determined by training status and genetic potential [3]. Agility is a complex motor ability, and in the background of the manifestation of agility are numerous other abilities, such as speed, power, coordination, balance, and even cognitive and perceptual capacities [4]. In general, the existence of two basic types of agility is widely accepted and scientifically proven; (1) change of direction speed or pre-planned, non-reactive agility (CODS) and (2) reactive, non-planned agility (RAG) [5,6]. CODS is evident in situations where the movement pattern is known in advance, while on the other side, in the RAG, agile movement is performed based on some external stimuli and cannot be pre-planned [7,8]. It is generally accepted that different factors influence these two agility manifestations. Briefly, while CODS is mainly determined by morphological and motor parameters, perceptual and cognitive skills are crucial in RAG [3,9].

Both facets of agility are present in sports, and their importance to situational efficiency and performance is confirmed [10,11]. Although it represents one of the most important motor skills in athletes, recently, its importance has been highlighted outside the competitive context [12,13]. In particular, agile movements are presented in professional activities (i.e., military, police), in everyday life, regardless of age, while performing unexpected reactions, overcoming obstacles, and, more specifically, solving perceptual-motor tasks during playing time [14,15,16].

Agility measurements among children are important for one specific reason. In particular, when performing agility tasks, a specific movement technique that differs from sport to sport plays a significant role [3,17]. This technique is developed through systematic, sport-specific training and will play a significant role in the performance of agility when testing adult athletes. Consequently, this will not give a precise picture of the abilities and skills that affect agility, regardless of movement efficiency. For this reason, it is necessary to analyze the predictors of the agile movement in the population of children, especially among the ones who do not engage in agility-saturated sports.

Several studies investigated the predictors of non-reactive, pre-planned agility in children not involved in specific sports [4,18,19]. For example, the study on early pubescent girls identified reactive strength as the most significant predictor, while body composition and anthropometrics had weak-to-medium correlations with reactive agility performance [18]. More recently, a study on early pubescent boys and girls analyzed the influence of balance, jumping, speed capacities, and several morphological variables on three different agility tests [19]. Results highlighted sprinting at 10 m, body mass, and high jumps as the most important predictors [19]. Additionally, a study on early pubescent boys investigated predictors in five different agility performances [4]. Predictors explained between 47% and 62% of the variance, with the two-leg lateral jumps recognized as the single best predictor [4].

Although studies already analyzed predictors of CODS, there is an evident lack of studies exploring the predictors of RAG among children. Meanwhile, RAG is known to be an important determinant of success in agility-saturated sports [7,20,21]. A better understanding of the background of RAG in children will hopefully result in a more accurate orientation of talented children toward agility-saturated sports (i.e., basketball, soccer, handball, tennis). Therefore, the main aim of this study was to determine the association between anthropometric/body composition indices, motor abilities (predictors), and RAG in early pubescent boys and girls. Knowing the differences in fitness status between prepubescent boys and girls, we tried to avoid the potential influence of gender as a covariate of established associations; therefore, a gender-stratified approach was applied. We hypothesized that the studied predictors would be significantly associated with RAG with some gender specifics.

2.3.2 Materials and Methods

Participants

Primary school boys (n = 73) and girls (n = 59) aged 11–12 years were involved in this study. In the first phase of the study, a sub-sample consisting of 21 participants was tested on newly developed tests throughout the test–retest procedure in order to evaluate the reliability of the tests (for details on reliability, please see the first part of the Results section). All participants were in good health and were regularly attending physical education classes (PE), while some of them were included in out-of-school sports. The inclusion criteria were: no evident motor aberrations and health-related issues (as indicated by school medical staff), no locomotor injury over a period of two weeks before testing, and regular participation in PE. Exclusion criteria were: recent musculoskeletal disorders, sickness over the previous two weeks, the current prevalence of pain, and/or overall sense of weakness, and three participants were excluded from the study accordingly.

The Ethical Board of the Faculty of Kinesiology University of Split, Split, Croatia, administered approval for the investigation (Ethical board number: 2181-205-02-05-22-0021). The participants were informed of the purpose of the study, and the written consent was signed by their parents or custodians.

Measures and Procedures

Variables in this study included predictors and criteria. The predictors consisted of anthropometric/body-built indices (body height, seated height, body mass, and body fat percentage), motor abilities (10 m sprint—S10M, and 20 m sprint—S20M, broad jump—BJ, squat jump—SJ, countermovement jump—CMJ, and drop jump—DJ, triangle test of change of direction speed—TCODS and 20 Yard shuttle agility test—20Y). The criterion variable was the originally developed "Triangle" test of reactive agility (TRAG).

Body height was measured using a Seca Instruments stadiometer. Body mass and body fat were assessed using a Tanita Pro MC-780U body composition analyzer (Tanita Corp., Tokyo, Japan), which provides a print-out of the measured body mass and calculated body fat. Information about the participants' gender, age, and body height was inserted into the device, and the participants had to stand barefoot in an upright, stable position. The device provided body mass and used an algorithm incorporating impedance, age, and height, to estimate the percentage of the total body fat.

A Brower timing system (Salt Lake City, UT, USA) was used for the assessment of S10 and S20, which is a commonly used and previously validated system [22]. Two electronic timing gates were placed 1, 11, and 21 m from the starting line. These photocells were mounted 1 m above floor level, which is the maximal height of the manufacturer's standard tripods. The participants ran as fast as possible for the required distance, with the self-chosen preferred leg placed on the starting marking.

For the 20Y, TCODS, and TRAG agility tests, BlazePod was used (Play Coyotta Ltd., Tel Aviv, Israel).

For TCODS and TRAG, three lighting pods were mounted on 50 cm cones in an equilateral triangle formation—equal sides, equal angles of 60° (Figure 1).

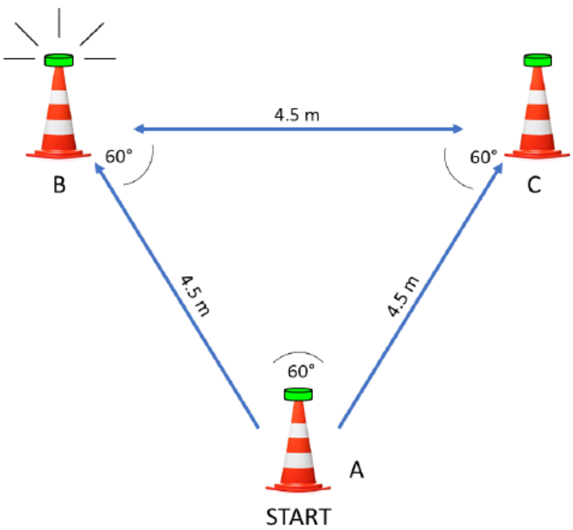

Figure 1. Scheme of the TRAG and TCODS testing.

To set the angles, a universal plastic goniometer with a 360° conveyor was used (1° accuracy, European Product). The distance between the cones was set at 4.5 m. In the TCODS test, the participants knew the scenario in advance (first trial: A–B–C, second trial: A–C–B), and after starting, they had to run from one cone to another and touch the lighting pods to turn off the lights. For the TRAG test, the participants did not have advanced knowledge of the scenario. However, all participants were tested by the same templates (first trial: A–C–B, second trial: A–B–A, third trial: A–C–A, fourth trial: A–B–C). The participants were instructed to begin the test with their preferred foot forward placed next to the starting cone. To start the TRAG, students should tap the first lighting pod (cone A), run to the next lighted cone, and touch the designated pod, which triggers the last cone. TRAG scenarios were applied in random order, but all participants were tested in all four scenarios. The testing was arranged in groups of 4–5 participants, which allowed for appropriate rest intervals between the tests and trials. The rest interval was not less than 20 s between trials.

For the 20Y test, three 50 cm cones, with lighting pods on top, were positioned along a line 4.57 m (5 yd) apart. Students would start with a two-point stance after touching the middle pod to run fast as possible, 4.57 m to the left. The subjects then ran 9.14 m to touch the illuminated cone on the right and finally finished by running back, touching the middle pod.

SJ, CMJ, and DJ testing were performed using the OptoGait system (Microgate, Bolzano, Italy). The software platform allows for the easy storage of all tests carried out and the ability to recall them instantly if necessary. Before the test, the participants were familiarized (the test procedure has been explained to the participants) with the procedure and had three attempts of each test. The students had to use maximal effort to achieve the best possible result. During the broad jump test, the participants stood on the starting line with their legs parallel and feet shoulder-width apart. They were instructed to bend their knees (the degree of flexion was determined by the participant) and bring their arms behind their bodies. A powerful drive was then used to propel them forward.

All measurements were performed on an indoor gymnasium with a wooden floor. Before testing, the participants completed a 10 min warm-up including jogging, skipping, lateral running drills, dynamic stretching, and light jumping. The testing protocol was the same for all participants. All of the tests were performed at the same time of day (9 to 11 a.m.) to prevent variations in the biorhythm and fitness abilities. The participants had one practice trial for familiarization with each test and performed it with self-chosen sports shoes. For the tests measured automatically by the Brower timing system, Optogait, and the Blazepod system, the same examiner assessed all participants.

Statistics

Statistical calculations included several groups of analysis. First of all, a Kolmogorov–Smirnov test was used to check the normality of distribution, and means and standard deviations were calculated for all observed variables. The reliability of the agility tests was checked by calculating Intra Class Coefficients (ICC). Student's T-test was used to evaluate the differences between the genders. To examine the univariate associations between the variables, the Pearson correlation coefficient was calculated. In the last phase, all significantly correlated variables were included in the multiple regression analysis to identify the predictors of the TRAG, separately for boys and girls. For all the analyses, Statistica 14.0 (TIBCO Software Inc., Palo Alto, CA, USA) was used, with a p-level of 95% in all calculations.

2.3.3 Results

The TRAG and TCODS tests showed appropriate inter-testing and intra-testing reliability (TRAG: ICC = 0.69 and 0.76, TCODS: 0.77 and 0.80 for inter-testing and intra-testing reliability, respectively).

The descriptive statistics and results of the Kolmogorov–Smirnov test of the normality of distributions for all variables are presented in Supplementary Tables S1 and S2 (for boys and girls, respectively).

Table 1 presents the results of univariate correlations for boys. Apart from the small and negligible correlation between BF and TRAG (less than 5% of the common variance), anthropometric/body-built indices were not significantly correlated to TRAG. However, practically all motor variables were significantly correlated to TRAG (6% to 60% of the common variance).

Table 1. Pearson's moment correlation coefficients between the studied variables for boys.

Var	AGE	BH	SH	BM	BF	BJ	S10	S20	20Y	TCODS	T RAG	SJ	CMJ	DJ
BH	0.36 *													
SH	0.41 *	0.66 *												
BM	0.18	0.66 *	0.53 *											
BF	−0.26 *	0.06	0.06	0.64 *										
BJ	0.36 *	0.18	0.20	−0.11	−0.52 *									
S10	−0.22	0.03	−0.02	0.34 *	0.54 *	−0.73 *								
S20	−0.21	0.03	−0.02	0.34 *	0.53 *	−0.74 *	0.98 *							
20Y	−0.26 *	−0.05	−0.02	0.23	0.42 *	−0.62 *	0.73 *	0.77 *						
TCODS	−0.22	−0.08	−0.12	0.23	0.47 *	−0.67 *	0.79 *	0.82 *	0.82 *					
TRAG	−0.18	−0.00	−0.07	0.21	0.27 *	−0.51 *	0.62 *	0.64 *	0.66 *	0.74 *				
SJ	0.27 *	0.20	0.26 *	−0.07	−0.50 *	0.78 *	−0.67 *	−0.67 *	−0.49 *	−0.56 *	−0.28 *			
CMJ	0.34 *	0.12	0.22	−0.18	−0.54 *	0.83 *	−0.73 *	−0.73 *	−0.51 *	−0.60 *	−0.35 *	0.92 *		
DJ	0.36 *	0.18	0.23	−0.10	−0.45 *	0.83 *	−0.81 *	−0.81 *	−0.55 *	−0.64 *	−0.46 *	0.87 *	0.91 *	
RSI	0.09	−0.00	0.04	−0.29 *	−0.50 *	0.69 *	−0.70 *	−0.68 *	−0.46 *	−0.54 *	−0.43 *	0.66 *	0.72 *	0.72 *

Legend: BH—body height, SH—seated height, BM—body mass, BF—body fat, BJ—broad jump, S10—10 m sprint, S20—20 m sprint, 20Y—20-yard shuttle agility test, TCODS—"Triangle" change of direction, TRAG—"Triangle" reactive agility, SJ—squat jump, CMJ—countermovement jump, DJ—drop jump, RSI—reactive strength index, * indicates the statistical significance of $p < 0.05$.

Among girls, anthropometric/body composition indices were not correlated with TRAG, while all motor indices except 20Y were significantly correlated with TRAG (10–39% of the common variance) (Table 2).

Table 2. Pearson's moment correlation coefficients between the studied variables for girls.

Var	AGE	BH	SH	BM	BF	BJ	S10	S20	20Y	TCODS	T RAG	SJ	CMJ	DJ
BH	0.19													
SH	0.38 *	0.79 *												
BM	0.23	0.59 *	0.57 *											
BF	0.15	0.19	0.25	0.81 *										
BJ	0.09	0.37 *	0.38 *	−0.11	−0.39 *									
S10	0.01	−0.14	−0.21	0.29	0.50 *	−0.74 *								
S20	0.11	−0.13	−0.17	0.28	0.52 *	−0.70 *	0.89 *							
20Y	−0.23	−0.43 *	−0.38 *	−0.02	0.24	−0.54 *	0.51 *	0.49 *						
TCODS	−0.20	−0.08	−0.30	0.14	0.33 *	−0.43 *	0.49 *	0.44 *	0.42 *					
TRAG	0.12	0.05	−0.13	0.13	0.27	−0.33 *	0.43 *	0.39 *	0.28	0.63 *				
SJ	0.04	−0.05	0.17	−0.27	−0.46 *	0.46 *	−0.50 *	−0.51 *	−0.38 *	−0.51 *	−0.50 *			
CMJ	0.02	−0.13	0.14	−0.22	−0.36 *	0.45 *	−0.54 *	−0.56 *	−0.41 *	−0.47 *	−0.54 *	0.93 *		
DJ	0.03	−0.01	0.19	−0.27	−0.41 *	0.46 *	−0.53 *	−0.54 *	−0.42 *	−0.50 *	−0.41 *	0.89 *	0.90 *	
RSI	0.00	0.01	0.08	−0.33 *	−0.47 *	0.48 *	−0.51 *	−0.59 *	−0.45 *	−0.45 *	−0.36 *	0.75 *	0.75 *	0.86 *

Legend: BH—body height, SH—seated height, BM—body mass, BF—body fat, BJ—broad jump, S10—10 m sprint, S20—20 m sprint, 20Y—20-yard shuttle agility test, CODS—"Triangle" change of direction, TRAG—"Triangle" reactive agility, SJ—squat jump, CMJ—countermovement jump, DJ—drop jump, RSI—reactive strength index, * indicates the statistical significance of $p < 0.05$.

When multiple regressions were calculated for boys, 64% of the variance was attributed to the TRAG, with TCODS as a single partial significant regressor (Table 3).

Table 3. Results of the multiple regression analysis for boys for TRAG as a criterion.

Predictor	β	SE of β	b	SE of b	t (64)	*p*-Value
TCODS	0.59	0.18	0.63	0.19	3.4	0.001
R = 0.80; R^2 = 0.64; Adjusted R^2 = 0.56; F (10.50) = 8.9; $p < 0.001$; St. Error of estimate: 0.35						

Legend: TCODS—"Triangle" change of direction speed, R—coefficient of the multiple correlation; R^2—coefficient of the determination; β—standardized regression coefficient; b—nonstandardized regression coefficient.

When the multivariate relationship between the predictors and TRAG was calculated for girls, 59% of the variance in the TRAG performance was explained. The significant partial predictors were TCODS, CMJ, and DJ, with better reactive agility in girls who perform better in CODS and jumping tests (Table 4).

Table 4. Results of the multiple regression analysis for girls with TRAG as a criterion.

Predictor	β	SE of β	b	SE of b	t (50)	*p*-Value
TCODS	0.66	0.13	0.97	0.20	4.9	0.001
CMJ	−0.86	0.31	−0.08	0.03	−2.8	0.01
DJ	−0.71	0.28	0.07	0.03	2.5	0.01
R = 0.76; R^2 = 0.59; Adjusted R^2 = 0.52; F (8.49) = 8.81; $p < 0.001$; St. Error of estimate: 0.39						

Legend: TCODS—"Triangle" change of direction speed, CMJ—countermovement jump, DJ—drop jump, R—coefficient of the multiple correlation; R^2—coefficient of the determination; β—standardized regression coefficient; b—nonstandardized regression coefficient.

2.3.4 Discussion

This study aimed to identify predictors of reactive agility among early pubescent boys and girls. There are several very important findings. First, anthropometric/body built indices were not correlated with TRAG in the studied children. Second, multivariate analysis evidenced TCODS as the only significant multivariate predictor of TRAG in boys. Meanwhile, in girls, in addition to TCODS, leg power was highlighted as a significant multivariate predictor. Therefore, our initial study hypothesis was confirmed.

Anthropometric/Body Composition Indices and Reactive Agility

Anthropometric/body built indices were already studied as being potential predictors of facets of agility in children, but almost exclusively in relation to pre-planned agility (e.g., CODS), and the findings were not consistent [4,19]. For example, in the study on early pubescent boys, Sekulić et al. found no significant correlation between observed anthropometry indices and five different pre-planned agility tests except for body mass and the Zig-zag test [4]. On the other hand, Pavlinović et al. reported a significant correlation between body mass and body fat with pre-planned agility in both boys and girls [19]. Meanwhile, to the best of our knowledge, this is the first study where anthropometric/body-built indices were observed as predictors of reactive agility. In short, apart from the negligible correlation between body fat and TRAG in boys (less than 5% of the common variance), anthropometric/body-built indices were not associated with TRAG in early pubescent children.

The first reason for the absence of an association between anthropometric/body composition and TRAG can probably be found in the duration of the test applied in our study. Namely, the test duration was very short (approximately 3 s). It, therefore, did not contain a significant energetic component, for which a higher body and fat mass would represent an important factor of influence. Second, it is widely accepted that reactive agility is more a complex ability than CODS, being under the influence not only of conditioning capacities and corresponding anthropometric/body built indices but also cognitive-perceptual abilities (REFS). As a result, simply mathematically/statistically, the percentage of the RAG variance which could be explained by anthropometrics/body built is reduced, resulting in negligible correlations observed herein. It is also important to highlight that our study observed participants (both boys and girls), who were mostly in the pre-peak high velocity (PHV) age. As a result, there was no significant difference between them in anthropometric indices that could affect RAG performance [23,24]. Consequently, we have found no evidence that anthropometric/body-built indices should be observed as significant predictors of RAG in this age group.

Motor Abilities and Reactive Agility

Analyzing the results of univariate correlation analyses, it is evident that all power-related variables significantly correlate with reactive agility in boys. The correlation coefficients ranged from 0.28 to 0.51 for jumping performance, 0.62 to 0.64 for sprinting, and 0.66 to 0.74 for TCODS and 20Y performances. However, multivariate analysis revealed TCODS as the only significant predictor of TRAG. Thus, we can confirm that TCODS in the here-studied boys was an indicator of "overall motor status". Actually, this is in accordance with previous studies where authors examined predictors of RAG in competitive athletes, where significant correlations between the sport-specific CODS and RAG performances were reported of professional futsal players, young soccer players, young tennis players, and rugby league professional players [25,26,27]. Another important element additionally explains the importance of TCODS in predicting TRAG. In brief, TCODS and TRAG had similar scenarios and consisted of similar movement patterns (please see Methods for details). While strong correlations between pre-planned and non-planned agility tests with the same movement patterns were well documented in previous studies, we have no doubt that it additionally contributed to the finding that TCODS was the only significant predictor of TRAG in this study [27,28,29].

While TCODS was a significant predictor of TRAG in girls as well, we have no doubts that the background of its influence on TRAG for girls is almost certainly very similar to the one previously discussed for boys. However, the indicators of lower body power (e.g., CMJ and DJ) were also significantly multivariately associated with TRAG among girls. The explanation of these associations should be found in the characteristics of the CMJ and DJ.

These two types of jumping are characterized by slow (CMJ) or fast (DJ) short-stretching cycles, during which, the muscle goes through the phases of eccentric, isometric, and, finally, concentric contraction [30]. In that context, the finding of significant influence on TRAG is not surprising as the same pattern of different types of muscle contraction is characteristic of agile stop-and-go movements, distinct for TRAG [31,32]. In particular, when performing such a movement, sudden deceleration with eccentric muscle contraction occurs first. After that, there is a short period of isometric contraction when the movement is stopped and, finally, concentric contraction occurs in the acceleration phase [3].

Gender Differences in the Prediction of the Reactive Agility Performance

From the perspective of our study, it is essential to discuss the differences in the prediction of TRAG between the genders. Specifically, lower body power significantly predicted TRAG among girls but not among boys. There are two possible explanations for such findings. The first one is "contextual" (i.e., differences in sports involvement between genders), while the second explanation is related to differences in the maturation process between boys and girls at that age.

In early puberty, boys are more involved in sports, specifically team sports that are saturated with agile movements [33,34,35]. For example, a study on a large sample of Australian adolescents from 12 to 16 years old, found that 78.5% of boys participate in organized sports compared to 66.1% of girls [35]. This is not only related to organized participation in competitive sports but also to "free play", where boys more often than girls participate in different team sports [36,37]. Consequently, it is reasonable to expect that the boys in our sample have a higher level of specific motor skills which are (systematically and non-systematically) developed throughout participation in team sports [38]. It will help them in agility tests structured as in this study (TCODS and TRAG had the same movement patterns). On the other hand, girls (who are not as engaged in sports as boys, and therefore are relatively less skilled than boys of the same age) will probably conduct TRAG while exploiting their power capacities.

Second, the differences in biological maturity can potentially have a significant role in our findings regarding gender differences in predictors of TRAG. Namely, it is known that girls mature earlier and enter accelerated growth and development phases before boys [39,40]. Consequently, differences in power capacities such as jumping and sprinting among girls are greater than among boys, i.e., they have a greater variance in power than boys. As a result, stronger girls exploited their capacities even in RAG.

Indeed, studies have shown a more significant influence of physical capacity on agility in relatively older and more mature participants [41,42]. For example, in the study on youth football players, Krolo et al. analyzed predictors of sport-specific agility [42]. The results showed that the observed predictors, i.e., sprinting and power capacities, explained the larger percentage of agility variance in older than in younger participants [42]. Additionally, a study on pubertal handball male players showed that in older players (post-peak height velocity (PHV) group), a more considerable proportion of handball-specific agility was explained with physical capacities compared to the pre-PHV group [41]. It was explained by the fact that early maturers experienced more dynamic morphological changes and were able to generate more force than their late-maturing peers [41]. It is also important to note that changes also occur in the cognitive aspect of maturation with neural adaptations, which are an essential part of reactive agility. This not only explains our findings but also directs future studies to include cognitive parameters as agility predictors. Supportively, recent studies undertaken in other sports highlighted the applicability of the Stroop test (i.e., a test that measures the delay in reaction time between congruent and incongruent stimuli) as an important determinant of various facets of success in sports, indicating the potential usefulness of such measurement tools in determining the predictors of RAG as well [43].

Predictors of Reactive Agility in Children in Comparison to Predictors of Reactive Agility in Athletes

When observing all previously discussed associations between predictors and RAG, and comparing them with previous reports on athletes, certain differences in correlations should be highlighted. First, previous studies performed with athletes reported RAG as being more influenced by sprinting and jumping capacities than we have found herein. Second, the correlation between CODS and RAG in children was evidently higher than the correlation between CODS and RAG in athletes. With regard to the objectives of our study, these issues are specifically discussed.

In our study (specifically for boys), sprinting and jumping were not multivariately associated with RAG, which was not the case in previous studies performed with athletes [7,42,44] However, this is at least partially a consequence of the selection of variables in our multivariate regression. Namely, in previous studies, anthropometric indices, sprinting and jumping capacities were most often analyzed separately for both RAG and CODS, while CODS tests were not involved in the analyses as predictors of RAG [7,42,44]. For example, a study with young soccer players highlighted power capacities, manifested through slow and fast short-stretching cycles as the factors contributing to RAG [42]. Additionally, a study on a sample of top-level futsal players evidenced anthropometric indices and reactive strength as predictors of performance on the futsal-specific reactive agility test [44]. However, as we said previously, CODS was not included as a predictor of RAG in these studies, which naturally increased the percentage of the variance that was explained by other observed characteristics and capacities. However, we must not ignore the fact that RAG and CODS are more correlated in the here-studied children than in athletes observed previously, and this will also be shortly discussed.

Indeed, the correlations between the same-scenario CODS and RAG in our study are much higher (0.63 for girls and 0.74 for boys) than the correlations between the same capacities in competitive athletes. For example, Sheppard et al. (2006) reported less than 10% of the shared variance between sport-specific CODS and RAG in Australian football players, while Scanlan evidenced a negligible correlation between RAG and CODS in basketball players [45,46]. In explaining such relatively small correlations between CODS and RAG in professional athletes, authors regularly concluded that RAG performance in professional, highly trained athletes is more influenced by perceptual and cognitive abilities than by athletic parameters (i.e., anthropometric/body built indices and conditioning capacities), which are known to be determinants of CODS [45,46]. This is mostly explained by the fact that highly trained athletes have already reached a high level of conditioning status throughout systematic training, and/or sport-selection process, while perceptual and cognitive capacities are mostly "inherited" and/or at least are not systematically and specifically trained throughout sports training. Our study indirectly supports such considerations. In brief, it seems that RAG is more influenced by basic motor abilities in children than in professional athletes, at least partially due to the greater variance of these abilities in the relatively untrained population compared to highly trained athletes involved in professional sports.

Limitations and Strengths of the Study

One of the study's limitations is the cross-sectional design. Therefore, a longitudinal approach and interventions are needed in future studies to obtain a clearer picture of the relations between the observed capacities. Additionally, we evidenced only a limited number of variables while not including some theoretically significant predictors of RAG (i.e., strength, flexibility, and cognitive and perceptive parameters). Finally, the sample of participants in this study was heterogenous; it included boys and girls from different sports. Thus, in the future, it is recommended to analyze agility predictors only on children that do not participate in agility-saturated sports.

To the best of our knowledge, this is the first study to evaluate the predictors of RAG among early pubescent boys and girls while evaluating the evidently important factors of RAG performance. Knowing the importance of RAG in competitive sports, we hope that our results will initiate further research.

2.3.5 Conclusions

Although the results of the correlation analysis showed a significant and relatively high association between all the observed motor parameters and RAG, multivariate analysis extracted CODS in both genders and sprinting/jumping among girls as the most significant predictors. Anthropometric indices were not factors of influence on RAG, which is most likely a consequence of the short duration of the RAG test applied herein and the participants' age (pre-pubescent children).

High correlations between CODS and RAG and a relatively high proportion of the explained variance of RAG indicate that RAG in this age group is probably more related to motor abilities than cognitive factors. However, it is clear that RAG should be observed as a complex, multifactorial ability. Therefore, future studies must include other abilities that could influence agility performance, primarily cognitive, perceptual, and decision-making parameters. Finally, our findings suggest that pre-pubescent and early pubescent children should be systematically trained on basic motor abilities to achieve fundamentals for further developing RAG.

Supplementary Materials

The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/children9111780/s1, Table S1. Descriptive statistics for boys' sample (N = 72); Table S2. Descriptive statistics for girls' sample (N = 58); Table S3. t-Test for independent samples between boys and girls.

Author Contributions

Data curation, V.P. and S.V.; Formal analysis, N.F. and D.S.; Funding acquisition, N.F. and S.L.; Investigation, V.P.; Methodology, V.P., S.V. and D.S.; Project administration, S.L.; Software, N.F. and S.L.; Writing—original draft, S.V. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee of the University of Split, Faculty of Kinesiology (Ethical board number: 2181-205-02-05-22-0021).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study. Parents provided written consent for the inclusion of their children in the research.

Data Availability Statement

The authors will provide data to all interested parties upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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2.4Cognitive and Motor Capacities Are Poorly Correlated with Agility in Early Pubertal Children: Gender-Stratified Analysis

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Cognitive and Motor Capacities Are Poorly Correlated with Agility in Early Pubertal Children: Gender-Stratified Analysis

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Abstract

This research aimed to identify relations of cognitive and power capacities with reactive agility in pubescent boys (n = 55) and girls (n = 46). Cognitive abilities were evaluated by the Stroop test, while the BlazePod system was used to evaluate agility performance conducting 20 yard shuttle and triangle tests of non-reactive (TCODS) and reactive agility (TRAG), respectively. Performance in jumping power was assessed through the squat jump (SJ), countermovement jump (CMJ), and drop jump (DHJ) utilising the Opto Jump system (Microgate, Bolzano, Italy), while sprinting ability over distances of 10 and 20 m was measured using a photocells system. A principal component was extracted from the four Stroop test variables using factor analysis. Forward stepwise multiple regression analysis was conducted separately for boys and girls to evaluate the multivariate relationships among the predictors and the criterion. Among boys, 80% of the TRAG variance was explained (MultipleR = 0.9), with TCODS and SJ as significant predictors (β = 0.53 and −1.01, respectively). For girls, the TCODS was the significant predictor (β = 0.65), explaining 43% of the variance (MultipleR = 0.65). These results show that (i) cognitive abilities measured with the Stroop

test were not a reliable tool for predicting TRAG, (ii) jumping power was a significant predictor of TRAG in boys, and (iii) TCODS was a significant predictor of TRAG in girls. The findings indicated that cognitive abilities do not significantly influence reactive agility in pubescent children. It seems that power features have a greater influence on reactive agility, particularly in boys who have more developed motor skills at this age compared to girls.

Keywords: CODS; RAG; Stroop test; squat jump; regression analysis; cognition

2.4.1 Introduction

Agility refers to the rapid alteration of velocity or direction in response to a stimulus, representing a key aspect of athletic performance [1]. This characteristic encapsulates two facets of agility: pre-planned, characterised by the change of direction speed (CODS), and non-planned, which involves reactive agility (RAG) [2,3,4,5]. It marks the contrast between movements executed in response to familiar patterns and those performed in reaction to unpredictable stimuli. The duality of agility highlights the fact that it depends on a wide range of fundamental capabilities, such as strength, power, coordination, and notably, cognitive and perceptual abilities [6].

The crucial role of agility in sports is more important than physical strength; it serves as a significant indicator of potential success across various sport disciplines [7]. This has induced scientific inquiry into identifying the determinants of agility, with the goal of improving prediction models that can accurately forecast sport performance. Studies have consistently demonstrated that while CODS is largely influenced by morphological and motor characteristics, RAG is linked with cognitive and perceptual capacities [8]. This distinction highlights the complex nature of agility and its crucial role in improving competitive effectiveness and performance.

Cognitive capacities, which include processes such as attention, memory, and decision-making, are crucial to an athlete’s ability to perform well under pressure [9]. These capacities are influenced by a wide range of factors including genetic predispositions, training, and overall mental well-being. Research on the relationship between cognitive abilities and reactive agility can be particularly interesting because it suggests that improved perceptual abilities can have a big influence on an athlete’s reactive agility [10].

The relationships between cognitive abilities and agility continue to be established by latest research, providing a deeper understanding of how these domains interact to influence athletic performance. For example, research has shown that specific cognitive predictors, such as spatial awareness and reaction time, are essential elements of RAG [11]. These results point to a mutually beneficial relationship in which cognitive training may improve RAG and help athletes to reach new levels of performance. In summary, agility is the result of a complex interaction between an athlete's physical and cognitive abilities, each working together to enable the athlete to meet the high standards of dynamic sports.

Studies conducted thus far have highlighted the importance of agility in sports, confirming the significant influence of CODS and RAG on success in sports [12]. The mentioned research has not only established the specific functions that physical characteristics play in athletic performance, but it has also created opportunities to investigate the relationships between agility and cognitive processes. Meanwhile, there is certain evidence suggesting that cognitive capacities, such as decision-making speed and perceptual speed, might have a substantial influence on agility performance, particularly in RAG [13]. These findings suggest that cognitive processes can improve an athlete's reactive agility by improving their ability to react to unpredictable stimuli.

However, the majority of research examining correlations between cognitive capacities and agility has predominantly focused on adult athletes. These investigations, to explore the link between cognitive abilities and agility, have been assessed mainly using the Stroop test and generic CODS and RAG tests in trained populations [14,15,16]. This focus has provided valuable data, but it has also identified a lack of research examining the link between the agility and cognitive abilities in puberty-age children who are still not involved in specific athletic training [17,18]. Enhanced comprehension of the underlying factors contributing to reactive agility (RAG) will facilitate the development of more precise tests for RAG and enable improved guidance for talented children towards sports emphasising agility. The aim of this study was to investigate the correlation between cognitive capacities, as measured by the Stroop test, as exploratory variables, and the assessment of reactive agility (RAG) as the criterion, in pubescent boys and girls. Exploring these connections in early pubertal children, who are at a crucial developmental stage, offers a unique opportunity to identify possible cognitive abilities that contribute to agility. It allows for the early detection of potentially talented individuals based on a wider range of indicators than physical ability alone.

2.4.2 Materials and Methods

Participants

A simple random sampling technique was used to choose one 7th grade and one 8th grade class with total of 101 students, comprising 55 elementary school boys (mean age 13.99 ± 1 years) and 46 girls (mean age 13.93 ± 1.05 years), all from the same city school in Split, Croatia. This was 54.74% of all

7th and 8th graders in the school and this sample percentage should represent the whole population of students of this age in the particular elementary school well. All participants were in good health and some were engaged in after-school sports, information on which was collected through the subjective statements of the participants. Since general medical examinations are required in Croatian elementary schools at the start of each academic year, the PE teacher's information about the participants' health was also evaluated. Additionally, all selected children regularly attended physical education classes. Out of 101 respondents, 68 individuals reported participation in organised sports. Among these, the majority (36 respondents) are involved in team sports. Additional activities include martial arts (13 participants), aesthetic sports and athletics (each with 7 participants), rock climbing (3 participants), and aquatic sports (2 participants). The rest of them, 33 respondents, were reported not to participate in organised training. The inclusion criteria stipulated no evident motor abnormalities, an absence of health-related issues (confirmed by the school's medical staff), no recent locomotor injuries within two weeks before testing, consistent involvement in physical activity, and reliable attendance records for physical education classes, as verified by the PE teachers. Certain individuals were excluded due to meeting exclusion criteria, which included recent musculoskeletal disorders, illness within the past two weeks, current discomfort, and/or feelings of weakness, all of which were assessed through verbal reports from respondents.

Approval for the investigation was obtained from the Ethical Board of the Faculty of Kinesiology, University of Split, Croatia (Ethical Board Number: 2181-205-02-05-22-0021). Participants were briefed on the study's objectives and potential risks, and verbal consent was obtained from them, while their guardians or parents provided written consent prior to participation.

Table 1. Displays the characteristics of the participants.

Sample	All (n = 101)	Girls (n = 46)	Boys (n = 55)
Variable	mean (95% CI) ± SD	mean (95% CI) ± SD	mean (95% CI) ± SD
Age (years)	13.96 (13.76–14.17) ± 1.02	13.93 (13.62–14.25) ± 1.05	13.99 (13.72–14.26) ± 1.00
OffT (s)	60.34 (58.81–61.86) ± 7.73	59.15 (57.33–60.98) ± 6.14	61.32 (58.95–63.70) ± 8.77
OnT (s)	72.81 (70.09–75.53) ± 13.78	72.51 (68.31–76.70) ± 14.13	73.06 (69.38–76.73) ± 13.61
Off + OnT (s)	133.14 (129.11–137.18) ± 20.44	131.66 (125.92–137.40) ± 19.34	134.38 (128.59–140.17) ± 21.42
On − OffT (s)	12.47 (10.69–14.25) ± 9.01	13.35 (10.38–16.33) ± 10.03	11.73 (9.54–13.92) ± 8.09
BH (cm)	166.72 (164.76–168.67) ± 8.90	164.18 (161.78–166.57) ± 7.29	168.91 (165.98–171.84) ± 9.64
SBH (cm)	86.42 (85.43–87.40) ± 4.49	85.98 (84.66–87.30) ± 4.01	86.80 (85.32–88.28) ± 4.88
BM (kg)	59.65 (56.22–63.08) ± 13.95	55.24 (51.34–59.14) ± 10.45	63.32 (58.08–68.57) ± 15.50
Bfat (%)	21.39 (20.03–22.74) ± 5.50	24.46 (22.81–26.11) ± 4.43	18.83 (17.13–20.52) ± 5.01
S10 (s)	2.07 (2.04–2.10) ± 0.15	2.11 (2.06–2.16) ± 0.15	2.03 (1.99–2.08) ± 0.15
S20 (s)	3.67 (3.59–3.74) ± 0.34	3.75 (3.65–3.86) ± 0.32	3.59 (3.48–3.70) ± 0.35
20Y BP (s)	4.98 (4.79–5.17) ± 0.85	5.14 (4.88–5.40) ± 0.79	4.84 (4.57–5.12) ± 0.89
TCODS (s)	2.74 (2.65–2.83) ± 0.40	2.81 (2.69–2.93) ± 0.35	2.68 (2.55–2.81) ± 0.43
TRAG min (s)	3.47 (3.37–3.58) ± 0.47	3.59 (3.45–3.72) ± 0.42	3.38 (3.23–3.53) ± 0.49
SJ (cm)	25.66 (24.38–26.95) ± 5.85	23.91 (22.19–25.62) ± 5.22	27.18 (25.36–29.00) ± 5.99
CMJ (cm)	26.28 (24.91–27.65) ± 6.23	24.17 (22.49–25.85) ± 5.10	28.11 (26.11–30.11) ± 6.59
DJH (cm)	25.23 (24.00–26.45) ± 5.58	23.71 (21.90–25.51) ± 5.50	26.54 (24.91–28.17) ± 5.36
RSI	0.93 (0.85–1.02) ± 0.40	0.87 (0.73–1.02) ± 0.44	0.99 (0.88–1.10) ± 0.37
PMS (s)	−0.00 (−0.20–0.20) ± 1.00	0.04 (−0.25–0.34) ± 0.99	−0.04 (−0.31–0.24) ± 1.01

Legend: OffT—psychomotor ability, OnT—response inhibition and motor speed, Off + OnT—composition measure of psychomotor speed and response inhibition, On − OffT—psychomotor speed, BH—body height, SBH—seated body height, BM—body mass, Bfat—body fat, S10—sprint 10 m, S20—sprint 20 m, 20Y BP—20 yards BlazePod, TCODS—triangle test change of direction speed, TRAG min—triangle test of reactive agility, SJ—squat jump, CMJ—countermovement jump, DJH—drop jump height, RSI—reactive strength index, PMS—psychomotor speed factor.

Measures and Procedures

Four anthropometric tests were conducted: body height (BH), seated body height (SBH), body mass (BM), and body fat (BFat). The ability to accelerate was tested with a 10 and 20 m sprint (S10 and S20). Agility was tested by conducting three tests: the 20yard shuttle agility test (20Y) and triangle test of change of direction speed (TCODS) were used to test generic agility, and the “triangle” RAG test (TRAG) to test reactive agility [19]. To evaluate muscular performance, the Opto Jump system (Microgate, Bolzano, Italy)—an optical measurement system for assessing jump performance and timing—was used for three tests: squat jump (SJ), countermovement jump (CMJ), and drop jump (DHJ). As a measure of explosive strength, the reactive strength index (RSI) was calculated; it is calculated by dividing the jump height by the ground contact time during the DHJ. The Encephal App Stroop application was used to assess the cognitive functioning of the participants [20]. The Stroop application was downloaded from the Google Play app store (Encephal App Stroop, version 2.0.7).

Height measurements (BH and SH) were obtained using a Seca Instruments stadiometer. Body mass (BM) and body fat percentage (BFat) were evaluated using a Tanita Pro MC-780U body composition analyser (Tanita Corp., Tokyo, Japan). This device provides a print-out of the measured body mass and calculates body fat. Participants' gender, age, and body height were inputted into the device, and participants stood barefoot in an upright, stable position. The device utilised impedance, age, and height to estimate the percentage of total body fat.

For the assessment of S10 and S20, a Brower timing system (Salt Lake City, UT, USA), a widely utilised and previously validated system, was employed [21]. Two electronic timing gates were positioned at intervals of 1, 11, and 21 m from the starting line. These photocells were installed 1 m above floor level, in accordance with the maximum height of the manufacturer's standard tripods. Participants were instructed to sprint as swiftly as possible for the specified distance, with their preferred leg positioned on the starting marking.

The BlazePod reactive light training system (Play Coyotta Ltd., Tel Aviv, Israel) was utilised for the 20Y, TCODS, and TRAG agility assessments. For the 20Y test, three 50 cm cones with lighting pods mounted on top were positioned along a line 4.57 m (5 yards) apart. Participants initiated the test from a two-point stance, beginning after touching the middle pod, and then sprinted as quickly as possible 4.57 m to the left. They subsequently ran 9.14 m to touch the illuminated cone on the right before concluding by returning and touching the middle pod.

To conduct the TCODS and TRAG tests, three lighting pods were affixed to 50 cm cones arranged in an equilateral triangle formation, with equal sides and angles of 60° (refer to Figure 1).

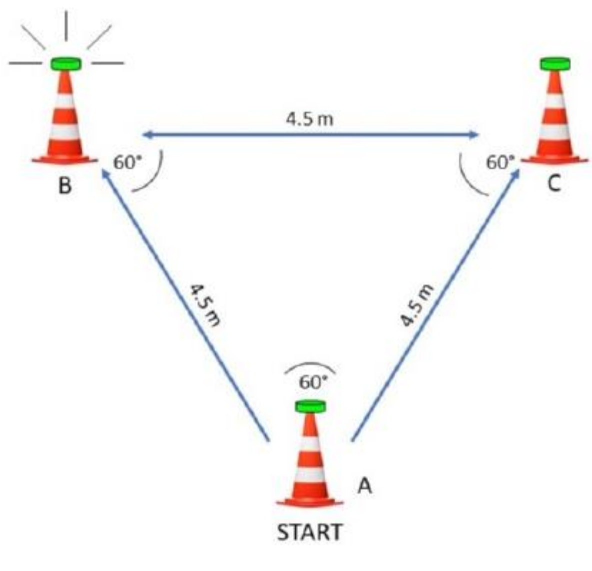

Figure 1. Scheme of the TRAG and TCODS testing.

To set the angles, a universal plastic goniometer with 360° accuracy and 1° precision (European Product) was utilised. The distance between the cones was standardised at 4.5 m. In the TCODS test, participants were familiarised with the scenario in advance (first trial: A–B–C, second trial: A–C–B), and upon initiation, they were required to move from one cone to another, touching the lighting pods to deactivate the lights.

For the TRAG test, participants were not informed of the scenario in advance (four different scenarios). Nevertheless, identical templates were employed for each participant's assessment. Participants were instructed to commence the test with their preferred foot positioned adjacent to the starting cone. To begin the TRAG, participants tapped the first lighting pod (Cone A), proceeded to the next illuminated cone, and touched the designated pod, which activated the last cone. TRAG scenarios were presented in a random order, with all participants undergoing testing in all four scenarios (Figure 1).

Testing was conducted in groups of 4–5 participants to allow for appropriate rest intervals between tests and trials. The rest interval between trials was no less than 20 s.

The assessment of SJ, CMJ, and DHJ was carried out using the Opto Jump system (Microgate, Bolzano, Italy), a sophisticated platform renowned for its precise measurements. The accompanying software allows for seamless storage of all test data and immediate retrieval when needed. Prior to testing, participants were briefed on the procedure through explanations and demonstrations, and they were given three practice attempts for each test to familiarise themselves with the process. Participants were encouraged to exert maximal effort during each attempt to achieve optimal results.

All measurements were performed in an indoor gymnasium with a wooden floor to ensure consistent testing conditions. Prior to the test, participants engaged in a 5 min warm-up routine consisting of running, light jumping, skipping, lateral running drills, and dynamic stretching. The testing protocol remained uniform for all participants, and tests were conducted at the same time of day (between 8:45 a.m. and 12:20 p.m.) to minimise variations in biorhythms and fitness levels. Participants were allowed one practice trial for each test, using their preferred sports shoes. For tests administered automatically by the Brower timing system, Opto Jump, and the BlazePod system, the same examiner assessed all participants.

Cognitive abilities were evaluated by the Stroop test using the Encephal App Stroop application [20,22,23]. The test was performed in the quiet, bright room with enough space between participants, so they could concentrate fully on the task and they were organised in groups of a maximum of nine pupils. The 7 inches tablet screens (HD C80 MeanIT, Zagreb, Croatia) were used to conduct the Stroop test. Before the test, the examination battery was thoroughly explained to the participants through a PowerPoint presentation by the trained researcher. Throughout the test, the researcher ensured its accurate and quiet conduct and responded to any additional questions. The participants reported no prior experience with the Stroop test.

The task encompassed two distinct components: the “Off” and the “On” states, contingent upon the congruence or incongruence of the stimuli. Each component followed two training runs. In the “Off” state, participants encountered a neutral stimulus, hashtag signs (###), presented in red, green, or blue, one at a time. Their objective was to swiftly touch the matching colour displayed at the bottom of the screen. These colours were randomised, not fixed to specific positions, and the task concluded after 10 presentations constituting one run. The total time taken for the run and individual responses were recorded. Any erroneous colour selections necessitated restarting the run, and achieving five correct runs marked the completion of the “Off” state.

In the “On” state, incongruent stimuli were introduced in nine out of ten instances. Here, participants were required to accurately select the colour of the word displayed, which differed from the actual name of the colour presented. For instance, if the word “RED” appeared in blue, the correct response would be blue, not red. Similar to the “Off” state, participants underwent two training runs, followed by task completion after achieving five correct runs.

The Stroop test yielded specific outcomes: OffTime: Total time for five correct runs in the “Off” state, primarily assessing psychomotor ability; OnTime: Total time for five correct runs in the “On” state, a measure of response inhibition and motor speed; OnTime minus OffTime: A measure of cognitive processing, controlling for psychomotor speed; OffTime plus OnTime: A composite measure reflecting both psychomotor speed and response inhibition.

2.4.3 Statistics

The distribution for all variables was confirmed to be normal through a Kolmogorov–Smirnov test. Descriptive statistical parameters are presented as means and standard deviations. Exploratory factor analysis was conducted to extract one principal component from the four Stroop test variables. Multivariate relationships among predictors and the criterion (TRAG) were evaluated via forward stepwise multiple regression analysis, conducted separately for boys and girls. Initially, multiple regression was computed using half of the observations (boys: $n = 28$, girls: $n = 23$; randomly selected validation sample). Subsequently, the regression model equations were applied to the remaining half of the observations (boys: $n = 27$, girls: $n = 23$; cross-validation sample). The actual performance scores of the cross-validation sample were correlated with their predicted (calculated) performance scores. Finally, a t-test for dependent samples was employed to compare the calculated and achieved performance scores. STATISTICA Version 13 (StatSoft, Tulsa, OK, USA) was utilised for all calculations.

2.4.4 Results

The factor analysis of the four Stroop variables resulted in the extraction of one significant principal component (Factor 1), explaining 83% of the total variance. The On − OffT had the lowest correlation with the principal component ($r = -0.79$), followed by OffT ($r = -0.85$). OnT and Off + OnT had the highest correlation with principal component (both $r = -0.99$). The extracted factor is defined as psychomotor speed and will be addressed in further text as PSM variable (Table 2).

Table 2. Factorial structure of psychomotor variables in the Stroop test.

Variable	Factor 1
OffT	−0.85
OnT	−0.99
Off + OnT	−0.99
On − OffT	−0.79

Legend: OffT—psychomotor ability, OnT—response inhibition and motor speed, Off + OnT—composition measure of psychomotor speed and response inhibition, On − OffT—psychomotor speed.

When multiple regression was performed for TRAG in the validation subsample of boys, the predictors accounted for 80% of the variance in the criterion. Significant partial regressors included T_CODS ($\beta = 0.53$) and SJ ($\beta = -1.01$). The regression model for TRAG obtained in the validation subsamples was as follows: TRAG = 2.11 + 0.65 × TCODS − 0.10 × SJ + 0.06 × DJH + 0.13 × 20Y BP. Upon applying the regression model to the cross-validation subsample, a common variance of 44% ($p < 0.05$) was observed between the calculated and observed scores. In the subsequent phase, a comparison of the calculated and observed scores for TRAG revealed no significant difference in the cross-validation subsample (3.37 ± 0.49 and 3.29 ± 0.35, $p = 0.43$; respectively). This confirmed the appropriateness of the regression modelling for TRAG in boys (Table 3).

Table 3. Forward stepwise linear regression of TRAG was conducted for the validation sample, separately for boys.

	β	SE (β)	b	SE (b)	t-Value	*p*-Value
Intercept			2.11	0.73	2.89	0.01 *
TCODS	0.53	0.14	0.65	0.17	3.80	0.00 *
SJ	−1.01	0.31	−0.10	0.03	−3.30	0.01 *
DJH	0.63	0.31	0.06	0.03	2.01	0.07
20Y BP	0.20	0.16	0.13	0.10	1.27	0.23
R	0.90					
R^2	0.80					
p	0.001					

Legend: TCODS—triangle test change of direction speed, SJ—squat jump, DJH—drop jump height, 20Y BP—20 yard BlazePod, β—regression coefficient, SE (β)—standard error of the regression coefficient, * indicates the statistical significance of $p < 0.05$.

When multiple regression was performed for TRAG in the validation subsample of girls, the predictors accounted for 43% of the variance in the criterion. The significant partial regressor was CODS (β = 0.65). The regression model for TRAG obtained in the validation subsamples was as follows: TRAG = 1.42 + 0.78 × TCODS. Upon applying the regression model to the cross-validation subsample, a common variance of 42% ($p < 0.05$) was observed between the calculated and observed scores. The calculated and observed scores for TRAG were compared using a t-test for dependent samples. No significant difference was found between the calculated and observed scores for the cross-validation subsample (3.70 ± 0.30 and 3.68 ± 0.40, p = 0.81, respectively). This confirmed the appropriateness of the regression modelling for TRAG in girls (Table 4).

Table 4. Forward stepwise linear regression of TRAG calculated for validation sample separately for girls.

	β	SE (β)	b	SE (b)	t-Value	*p*-Value
Intercept			1.42	0.71	1.99	0.07
TCODS	0.65	0.20	0.78	0.24	3.22	0.01 *
R	0.65					
R^2	0.43					
p	0.006					

Legend: TCODS—triangle test change of direction speed, β—regression coefficient, SE (β)—standard error of the regression coefficient, * indicates the statistical significance of $p < 0.05$.

2.4.5 Discussion

Correlates of Cognitive Abilities and Agility

The majority of studies dealing with this issue were conducted on athletes in team sport games. In those studies, cognitive abilities were supposed to be a very important facet in successful reactive agility performance. According to Young et al. (2015), the importance of the cognitive element in agility, particularly in team sport games, plays a crucial role, with RAG tests being better at discriminating between higher- and lower-standard athletes than CODS tests [6]. Additionally, Scanlan et al. (2014) state that cognitive abilities, especially response time and decision-making, have been consistently identified as key factors in reactive agility performance in adolescent basketball players [17]. These findings are further supported by Zwierko et al. (2022), who found that the complex reaction time, which belongs to perceptual capacities, significantly contributes to reactive agility in young male volleyball players [24,25]. Despite the huge amount of studies declaring cognitive abilities as an important factor influencing reactive agility performance, our research did not confirm these findings. Psycho-motor speed variables measured with the Stroop test did not predict results in generic reactive agility in girls or in the boys' sample.

To the best of our knowledge, there is just one study that researched the relations of cognitive abilities and reactive agility in untrained youth subjects. Horička et al. (2020) estimated the cognitive capability of adolescent boys and girls with the Stroop test and did not find a significant relationship between reactive agility and cognitive abilities [18]. Actually, the correlation between reactive agility and cognitive abilities was very weak ($r = -0.12$). The authors assume that in the non-sporting adolescent population, these abilities are not sufficiently developed, as in sport populations, to justify their conditionality. Therefore, we may conclude that in our study, reactive agility performance was supported primarily by motor skills rather than cognitive abilities.

Correlates of Power Abilities and Agility

Although some authors have reported poor relationships between power qualities and agility performance, the majority of previous research found positive correlations [26,27,28]. In studies conducted on both young and adult athletes, researchers stress that agility, speed time, and jumping ability belong to the same physical attribute [29,30,31,32]. From all measured power indices in our study, only the squat jump test proved to be significant predictor of reactive agility in the boys' sample. Results like this are consistent with the literature review. For example, Köklü et al. (2015) found a strong correlation ($r = -0.71$) between SJ and the zigzag agility test performed without the ball in young soccer players [33]. The authors explained this through the similarity of muscle actions and short duration in both tests; namely, to perform a jump or to change the direction of movement, one needs to use a lot of muscle power in a short period of time [1]. According to the results of our study, we may say that more powerful preadolescent boys perform better on a generic reactive agility test. In previous research, authors found positive effects of jumping training on agility performance. Obviously, plyometric training enhances muscle neural adaptations and the enhancement of motor unit recruitment [34,35]. Both features are very important for fast and effective change of direction movements. We assume that those features, along with those mentioned before, make a difference between a good and bad agility performer of this particular age and gender.

Linear regression calculation did not find any significant power predictor for reaction agility in the girls' sample. Apparently, the girls' results in the TRAG test are possible to predict only with the CODS test. Therefore, it is expected that girls rely less on power and more on some other motor qualities to execute this specific reactive agility task. Actually, several authors have proposed that different agility manifestations in pubescent girls should be observed as relatively independent qualities since the percentage of the common variance between the observed agility tests rarely exceeded 50% [18,36].

The absence of running speed influence on reactive agility performance in both genders should be contextualised with TRAG test movement characteristics. During the TRAG test, subjects move short distances (4.5 m between the polygons' cones) and are not able to develop any significant linear speed such as during sprinting tests. Also, the number of steps in the TRAG test ranges from 3 to 5, and those steps are pretty short due to the speed decrement and accelerations during stop-and-go movements. Contrarily, during sprint tests, subject move larger distances (10 to 20 m) which they cover with 10 to 15 steps. One of the studies that corroborates our assumption was conducted by Born et al. (2016). The authors found that sprinting ability can enhance CODS and RAG in young football players only if trained in a multidirectional manner and over distances similar to those in agility tests [37].

Correlates of Non-Reactive and Reactive Agility

Along with other tests, two generic non-reactive agility tests were involved in regression analysis calculation: CODS and 20Y BP. In both samples, only CODS proved to be a significant predictor of the TRAG result. It can be stated that if performed on the same polygon, the generic agility test is highly influential on reactive agility performance in pubescent boys and girls. This finding agrees with the literature review. Thus, Krolo et al. (2020) found significant and strong correlations between specific football CODS and RAG tests in young football players. The correlations were stronger in the older age category (U13; $r = 0.42$, U15; $r = 0.58$). This analysis leads to the conclusion that the younger group lacked the specific skills required to effectively perform CODS and RAG manoeuvres [38]. The authors posited that a direct consequence of longer involvement in football and systematic training is that the older group possesses a higher level of skill. This elevated skill level enables them to effectively perform RAG and CODS manoeuvres while also incorporating the necessary conditioning capacities.

In our research, we did not have a different age category but different genders. We can assume that boys are much more familiar with stop-and-go movements since they practice it through organised and unorganised sport games much more than girls do. Boys are inclined more toward playing team sports games such as football, basketball, or handball, which are saturated with stop-and-go movements [39,40,41]. That is the most likely cause why CODS explained a significantly higher proportion of RAG in boys (80%) than in the girls' sample (43%).

Due to the relatively small portion of shared variance observed in the girls' sample, the authors suggest that a significant portion of reactive agility variance is likely influenced by independent factors not examined in this study. Prior research indicates that such factors could include factors like balance, mobility, perception, or intelligence [18,36]. Furthermore, participants were selected based on gender criteria, leading to considerable diversity among them, with some engaging in agility-focused sports while others did not. To some extent, this could provide noisy data and limit the study's conclusive generalisations. The primary constraint of this study lies in its cross-sectional design, necessitating intervention studies to elucidate the causal relationships between the variables under scrutiny. Additionally, future research should delve into unexplored factors potentially affecting RAG performance, such as intelligence or perception. Future research should focus on competitive young athletes and consider factors such as practice duration, weekly frequency, and competition level to deepen our understanding of how cognitive abilities, power, and reactive agility are interconnected. Despite the acknowledged limitations, this study is among the first to utilise highly reliable assessment tools (Opto Jump, BlazePod, Power Timer system) to evaluate power, agility, and cognitive abilities in school children with the primary objective to identify the connections and potential influences among these variables. The gathered data could be used not only to explore the impact of cognitive abilities on RAG performance but also to better our understanding of gender disparities in power abilities during this critical phase of motor development.

2.4.6 Conclusions

This is likely one of the first studies that has examined correlations between cognitive capacities, speed/power abilities, and generic reactive agility in pubescent girls and boys. The primary aim of this study was to examine the connections between cognitive abilities, treated as exploratory variables, and generic reactive agility, considered as the criterion, in pubescent girls and boys. With this objective, the research has three major findings: (i) Our results indicate that cognitive abilities, measured by the Stroop test, are not a reliable tool for predicting results on the TRAG test among pubescent students. (ii) Jumping power is a significant predictor of generic reactive agility exclusively in the boys' sample. (iii) CODS is the only variable that can be used as a predictor of generic reactive agility in pubescent girls. The findings of the research indicate that in elementary school pubescent boys and girls, cognitive abilities do not play a significant role in reactive agility performance. It seems that speed and power features have a greater influence on RAG, particularly in boys who have more developed motor skills at this age. The data obtained indicate a necessity for delving deeper into understanding how cognitive abilities influence reactive agility, which is the primary contribution of the study to the domain of agility development and training. Nevertheless, PE teachers and coaches that work with pubertal age children should not neglect the possible influence of cognitive abilities on reactive agility performance. Hence, training this ability should always contain cognitive-perceptual effects such as reactions to unpredictable visual, kinaesthetic, or audio stimuli.

Author Contributions

Conceptualisation, N.F. and V.P.; methodology, T.G., F.M., N.K. and V.P.; software, F.M.; formal analysis, N.F., T.M. and N.K.; investigation, T.G., F.M. and V.P.; data curation, V.P.; writing—original draft preparation, V.P. and N.F.; writing—review and editing, T.G., L.L.K., F.M. and T.M.; supervision, N.F. and L.L.K.; project administration, V.P. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee of the University of Split, Faculty of Kinesiology (Ethical board number: 2181-205-02-05-22-0021).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study. Parents provided written consent for the inclusion of their children in the research.

Data Availability Statement

The authors will provide data to all interested parties upon reasonable request.

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Conflicts of Interest

The authors declare no conflicts of interest.

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3. ZAKLJUČAK

Priloženi radovi nastali su kao rezultat rada na HRZZ projektu (DOK-2021-02) pod nazivom koji je identičan naslovu ove doktorske disertacije; "*Predplanirana i reaktivna agilnost kod djece u pubertetu i ranom pubertetu; objektivizacija mjerenja, predikcija i razvoj*" (IP-2018-01-8330). Svi radovi proučavaju različite aspekte agilnosti kod djece, s naglaskom na utjecaj, povezanost i prediktore agilnosti. Rezultati su pokazali nekoliko važnih zaključaka koji će biti navedeni redoslijedom koji prati priložene radove: (I) tjelesna masa, visina skoka i brzina trčanja značajno utječu na pred-planiranu agilnost, uz varijacije između dječaka i djevojčica, pri čemu je brzina prikazana kao ključni prediktor predplanirane agilnosti kod djevojčica; (II) novokonstruirani test TRAG je valjan i pouzdan za mjerenje reaktivne agilnosti; (III) brzina i eksplozivna snaga identificirani su kao ključni prediktori reaktivne agilnosti u ranom pubertetu; (IV) kognitivne i motoričke sposobnosti nisu značajno povezane s agilnošću.

Zaključci svakog rada opširno su i detaljno objašnjeni u priloženim radovima. Da bi se izbjeglo ponavljanje, ispod su sažeti u nekoliko rečenica.

U prvom radu, razlike u utjecaju tjelesne mase, visine skoka i brzine trčanja na agilnost dječaka i djevojčica ukazuju na potrebu za prilagođavanjem programa treninga agilnosti s obzirom na spol. Razumijevanje dobivenih rezultata i razlika između dječaka i djevojčica može biti od pomoći trenerima i profesorima tjelesne i zdravstvene kulture u razvijanju učinkovitijih programa treninga za poboljšanje agilnosti kod djece.

Drugi rad pokazuje da je novokonstruirani TRAG test valjan i pouzdan za mjerenje reaktivne agilnosti kod dječaka i djevojčica, što ga čini korisnim testom za procjenu agilnosti u školskom okruženju i nastavi TZK. Uz to, test je jednostavan za provođenje i zabavan za izvođenje, što predstavlja dodatni motivacijski faktor za učenike.

U trećoj studiji, brzina i eksplozivna snaga identificirane su kao ključni prediktori reaktivne agilnosti u ranom pubertetu. Ovakvi rezultati naglašavaju važnost za uključivanje vježbi usmjerenih na razvoj brzine i eksplozivne snage u programe treninga, sportske treninge i satove TZK. Također, ovi rezultati mogu poslužiti trenerima i profesorima u školama kako bi kreirali učinkovitije i prilagođenije programe treninga koji će poslužiti za optimalan razvoj agilnosti kod djece u pubertetu i ranom pubertetu. Povećanjem navedenih sposobnosti može se utjecati na poboljšanje reaktivne agilnosti, što je od iznimne važnosti za sportove koji zahtijevaju brze promjene smjera kretanja i reakcije na vanjske podražaje.

Zaključak četvrte studije upućuje na to da kognitivne sposobnosti nemaju značajniju ulogu u izvedbi reaktivne agilnosti kod dječaka i djevojčica. Brzina i eksplozivna snaga imaju veći utjecaj na reaktivnu agilnost, osobito kod dječaka, koji u ovoj dobi imaju razvijenije motoričke sposobnosti. Rezultati upućuju na potrebu za usmjeravanjem programa treninga na poboljšanje fizičkih sposobnosti kako bi se agilnost unaprijedila. Dobiveni rezultati ukazuju na potrebu za daljnjim istraživanjem, uključujući upotrebu nekih drugih kognitivnih testova, kako bi se bolje razumio utjecaj kognitivnih sposobnosti na reaktivnu agilnost djece u pubertetu i ranom pubertetu.

3.1 Ograničenja istraživanja

Jedno od glavnih ograničenja ovog rada je uzorak koji nije u potpunosti sastavljen od djece koja se ne bave sportovima koji zahtijevaju agilnost. To je praktično nemoguće postići, jer su osnovnoškolska djeca te dobi većinom uključena u sportske klubove, sudjeluju u školskim sportskim aktivnostima ili se igraju na školskim igralištima pri čemu koriste agilne pokrete. Dodatno, djeca koja su se izjasnila da se ne bave sportom većinom su bila djeca koja u tom trenutku nisu uključena u sportske klubove. Ipak, većina djece ima sportski staž od nekoliko godina treniranja određenog sporta. Razlozi za prekid redovitog treniranja su raznoliki; uključujući nedostatak vremena, brojne školske obaveze i zasićenje trenutnim sportom. Djecu koja su potpuno fizički neaktivna nisu bila predmet ovog istraživanja jer nije bilo potrebno proučavati takvu populaciju.

Test TRAG koji smo koristili mogao bi biti sofisticiraniji u smislu složenosti i uključivanja različitih tipova agilnih kretanja. Međutim, cilj je bio konstruirati test koji je jednostavan za provođenje na satu TZK.

Za procjenu kognitivnih sposobnosti koristili smo isključivo Stroop test, što može ograničiti točnost rezultata. Iako se Stroop test često koristi u literaturi i na različitim populacijama (Horička, Šimonek, & Paška, 2020; Lovecchio i sur., 2021; Naylor i Greig, 2015), ostaje pitanje mjeri li on one kognitivne kapacitete koji mogu utjecati na reaktivnu agilnost.

3.2 Smjernice za buduća istraživanja

Buduća istraživanja trebala bi obuhvatiti više škola u različitim regijama kako bi se povećala reprezentativnost uzorka, što bi omogućilo generalizaciju rezultata. Reaktivna agilnost je nedovoljno istražena u populaciji koju smo proučavali, što je istaknuto u uvodu ove disertacije, stoga bi se na tu temu trebalo više fokusirati. Iako smo u našem istraživanju reaktivne agilnosti koristili relativno veliki broj prediktora, ostaje prostor za daljnja istraživanja onih koje nismo uključili, kao što su koordinacija, ravnoteža, fleksibilnost i mobilnost. Također, suradnja s ekspertima iz drugih područja – prvenstveno psihologa i neuroznanstvenika – bila bi korisna za odabir različitih testova kognitivnih sposobnosti. Potrebno je provesti daljnja istraživanja kognitivnih sposobnosti koristeći različite testove kako bi se bolje razumjeli njihov utjecaj na reaktivnu agilnost.

4. ŽIVOTOPIS

Vladimir Pavlinović, rođen je 25. rujna 1982. u Dubrovniku, Hrvatskoj. Paralelno s osnovnom i srednjom školom, koje je završio u Splitu, aktivno je trenirao tenis i taekwondo. Upis na Kineziološki fakultet u istom gradu bio je logičan slijed događaja. Diplomirao je 2008. godine s usmjerenjem iz Osnovnih kinezioloških transformacija. Već tada je bio najviše zainteresiran za kondicijsku pripremu, a isto područje interesa zadržao je do danas.

Još za vrijeme studija, počeo je raditi kao taekwondo trener u danas popularnom klubu Marjan iz Splita. Također, u isto vrijeme radio je kao trener u poznatijem fitness centru u Splitu. Sve više interesa pokazivao je za kondicijsku pripremu sportaša, dok se istovremena taekwondo, počeo pretvarati u neki novi, drugačiji sport. Postupno se udaljavao od treniranja taekwondoa u klubu i posvetio se kondicijskoj pripremi profesionalnih i manje profesionalnih sportaša.

Kroz godine rada imao je sreću surađivati sa vrhunskim sportašima, što mu je omogućilo kontinuirano učenje i napredovanje. Posebno kroz razgovore o metodama treninga koje su sportaši provodili sa svojim trenerima u reprezentaciji i u klubovima. Preporukom dobrih ljudi dobio je priliku raditi kao glavni kondicijski trener u tenis klubu u Rusiji, gdje je ostao pola godine, 5 mjeseci više nego što je bilo potrebno. Nekoliko godina za redom, radio je sa vaterpolistima Mornara, kako bi bili u najboljoj formi za nadolazeću sezonu. Surađivao je s najboljim odbojkašem kojeg je hrvatska ikad imala, kao i sa splitskim, zlatnim taekwondo blizankama...

Priliku za rad na projektu agilnosti i kao asistent na Kineziološkom fakultetu u Splitu dobio je 2021. godine gdje je trenutno i zaposlen.

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