UNIVERSITÀ
DEGLI STUDI
FIRENZE

DOTTORATO DI RICERCA IN SCIENZE BIOMEDICHE

CICLO XXXVI°

COORDINATORE Prof. Fabrizio Chiti

Efficiency In Kinesiology across developmental age and youth individual sport performance
Innovative Approaches to Enhance Motor Skills

Settore Scientifico Disciplinare BIO/09 – M-EDF/02

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Anni 2020 – 2023

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Thesis Summary

The Chapters within this dissertation are not interconnected by methodological commonalities, but rather bound by a shared conceptual ethos. Each investigation, while distinctive in its subject matter, adheres to a broader commitment, namely the pursuit of novel approaches in enhancing motor skills during developmental years, both regarding general motor proficiency as well as athletic performance. In doing so, this thesis aspires to not only enrich academic discourse but, more crucially, to empower practitioners (teachers, educators, trainers) in their respective field of expertise. This unified framework is the main effort of my thesis, the driving force that underscores my research endeavors. Within this conceptual tapestry, each Chapter contributes as a subordinate effort, weaving its content while aligning with the main effort. Still, there are some recurrent and consistent elements I adopt throughout this varied dissertation, which are the ecological, lab-independent, cost-effectiveness, and quasi-non-invasive approaches.

By adopting an ecological perspective, I seek to mirror real-world scenarios, ensuring that findings resonate with the practicalities of diverse settings. The lab-independent approach signifies a departure from confined laboratory setups, embracing a broader canvas that mimics the dynamic and unscripted nature of real-world motor skill acquisition. The emphasis on cost-effectiveness aligns with the imperative of resource optimization, acknowledging the practical constraints often faced by educators and coaches. The commitment to quasi non-invasive methodologies underscores the ethical considerations inherent in human studies, ensuring that the research interventions remain respectful of the individuals, i.e., almost always children or teenagers, participating in the studies.

The presented thesis unfolds on two distinct fronts. The first front is dedicated to the study of enhancing motor proficiency in the context of late childhood, as elucidated in Chapters 2 and 3. Specifically, Chapter 2 explores the intricate relationship between gross and fine motor skills in the context of late childhood, and whether and how leveraging on the gross motor domain could help enhancing fine motor abilities. Chapter 3 is comprised of two experiments, inquiring about the efficacy of segmentary, specific visual instructions for enhancing gross and precision motor tasks, respectively.

The second front of this thesis is dedicated to youth individual sport performance, with a focused analysis on track and field (Chapter 4) and swimming (Chapters 5-6), sports were the major bio-motor abilities (i.e., strength, power, stamina) play a paramount role in affecting the final outcome. Specifically, Chapter 4 delves into the nuanced realm of resistance training, utilizing velocity-based techniques to optimize training loads for

sprinters. Chapter 5 examines the interplay between maximum force-velocity exertion and swimming performances across various strokes and distances. Chapter 6 investigates the effects of different post-competition recovery protocols and their impact on physio-psychological parameters in national-level youth swimmers. Finally, Chapter 7 closes this thesis by discussing the approach presented here in a general context along with some concluding remarks and possible future directions.

I capitoli inerenti a questa dissertazione non sono accomunati da un punto di vista strettamente metodologico, ma legati da un ethos concettuale condiviso. Ogni indagine di ricerca, distinta nel suo oggetto, si attiene ad un disegno più ampio, ovvero lo sviluppo e la proposta di approcci innovativi al fine di migliorare le abilità motorie durante l'età dello sviluppo. Questo concetto viene esplicitato sia relativamente alle competenze motorie generali, che alle performance sportive. Seguendo questa cornice sperimentale, la tesi aspira ad "equipaggiare" gli operatori sul campo (insegnanti, educatori, allenatori) con nuovi (ed efficienti) concetti e strumenti sperimentali, da implementare nelle loro attività professionali per migliorarne la gestione e la qualità. In questo contesto, ogni capitolo contribuisce in maniera subordinata al già citato scopo principale. Vi sono, tuttavia, elementi ricorrenti nell'eterogeneità degli argomenti trattati, ovvero l'approccio ecologico, indipendente dal laboratorio, economico, e (quasi) non invasivo.

La prospettiva ecologica permette una riflessione su scenari del mondo reale, garantendo che i risultati siano attinenti con le praticità dei diversi contesti. L'approccio indipendente dal laboratorio determina un distacco da impostazioni confinate e "non familiari" ai soggetti presi in esame, operando in contesti che imitino la natura dinamica e non "pre-determinata" dell'acquisizione delle abilità motorie nel mondo reale. Gli aspetti di economicità si allineano con il concetto di ottimizzazione delle risorse, riconoscendo vincoli e restrizioni spesso affrontati da educatori/allenatori. Infine, l'utilizzo di metodologie quasi non invasive rimarca le considerazioni etiche inerenti agli studi su soggetti umani, mantenendo le ricerche rispettose di tutti i bambini e gli adolescenti che hanno partecipato agli studi.

La tesi di seguito presentata si sviluppa su due fronti distinti. Il primo fronte è dedicato allo studio del miglioramento delle competenze motorie nell'età della tarda infanzia (ciclo scuola elementare), come descritto nei Capitoli 2 e 3. In particolare, il Capitolo 2 esplora la relazione tra abilità motorie grossolane e fini. In particolare, se e come fare leva sull'esercizio grosso-motorio possa migliorare le abilità motorie fini. Il Capitolo 3 è composto da due esperimenti, che indagano circa l'efficacia di istruzioni visive segmentate e specifiche per il miglioramento di compiti motori di precisione (esperimento 1) e grossolani (esperimento 2), rispettivamente.

Il secondo fronte di questa tesi è dedicato al miglioramento delle performance nello sport individuale giovanile, con un'analisi focalizzata sull'atletica leggera (Capitolo 4) e il nuoto (Capitoli 5-6), sport in cui le principali abilità bio-motorie (cioè forza, potenza, resistenza) svolgono un ruolo predominante nell'influenzare l'esito finale della prestazione. In particolare, il Capitolo 4 approfondisce il campo dell'allenamento contro-resistenza, utilizzando strumenti e tecniche basati sulla velocità per ottimizzare i carichi di allenamento in giovani velocisti. Il Capitolo 5 esamina l'interazione tra espressione massimale di forza-velocità e performance natatoria, analizzati attraverso diversi stili e distanze di nuoto. Il Capitolo 6 esplora invece gli effetti di diversi protocolli di recupero post-competizione, ed il loro impatto sui parametri fisio-psicologici di giovani nuotatori di livello nazionale. Infine, il Capitolo 7 chiude la tesi discutendo l'approccio finora presentato in un contesto generale, con alcune osservazioni conclusive e possibili direzioni future da intraprendere.

1. Introduction

The historical evolution of kinesiology research reflects a path marked by continuous exploration and discovery. Originating from a primarily anatomical and physiological focus, and initially characterized by reductionist approaches that isolated specific aspects of movement, early kinesiological inquiries laid the groundwork for subsequent interdisciplinary approaches (Uygur, 2020). Over time, the field of kinesiology embraced biomechanics, psychology, neuroscience, and education (among many others), weaving together a rich tapestry of knowledge (Uygur, 2020). Nowadays, in fact, contemporary research has shifted towards a more integrative and holistic perspective, emphasizing both the interconnected nature of motor skills with other domains of proficiency, as well as the need to facilitate a comprehensive understanding of motor performance from multiple standpoints (Quarta et al., 2020; Zhao, Mao and Tan, 2022; Sorgente and Minciacchi, 2023). This approach has been instrumental in the development of targeted strategies and comprehensive interventions for enhancing motor skills with diverse strategies, such as the integration of cognitive training, perceptual-motor exercises, and adaptive technology (Li and Smith, 2021; Myszka, Yearby and Davids, 2023; Chen, Kwok and Li, 2023). This approach has been proven to be especially compelling when applied to young populations, as they are in the crucial stages of neuromotor development and tend to be highly responsive to external stimuli and training methods (Sorgente et al., 2021).

As mentioned in the title, the concept of "efficiency" in kinesiology research is central to the optimization of experimental practices and the multifaceted benefits of enhancing movement proficiency, especially in developing populations. Within the framework of efficient motor performances, “smoothness” is a widely recognized feature of healthy, proficient movement (Kiely, Pickering and Collins, 2019). In particular, smooth movements are characterized by a lack of jerky or abrupt transitions between different phases of a motor task, and according to this definition, the characteristic of smoothness can contribute “quality” or “fluidity” to the motion (Balasubramanian et al., 2015). Although movement smoothness can be measured with objective parameters, e.g., postural sway (Olivier, Palluel and Nougier, 2008), rate of change of acceleration (defined as “jerk”) (Roren et al., 2022), velocity profiles (Zhang et al., 2022), curvature analysis in the context of path-based movements (Cohen, Bravi and Minciacchi, 2021), it is often recognized as “aesthetically pleasing”, “fluid”, “graceful”, and may positively influence how a performance is perceived by others (Nam et al., 2014). This concept is particularly relevant in sports, physical exercises, and more generally in skilled tasks. Indeed, many sports and physical activities experts associate smoothness with expertise and competence (Gulde and Hermsdörfer, 2018). Smoothness (or one or more of its synonyms) is even referenced to as a judging criterion in sports/disciplines such as ballet, gymnastics, diving, ice-skating, etc. (McFee, 2013) From a mechanical and energetical standpoint, smooth movements often require less energy expenditure compared to erratic or jerky motion, minimizing unnecessary energy consumption (Pyne and Sharp, 2014). Even when the energy expended is comparable or even greater than that in a jerky motion, it is consistently done with the aim of achieving the task's goal more effectively (e.g., running or swimming faster, achieving better parameters during gait; Hreljac, 2000). Moreover, smoothness is often associated with better control and precision in executing movements, as it allows for fine-tuned adjustments, essential in activities that require accuracy and coordination (Cohen, Bravi and Minciacchi, 2018b). For these reasons, the acquisition of smoothness can often carry out and facilitate motor learning. This is especially significant during the initial stages of skill acquisition and development (i.e., for beginners in a sport or younger populations), when individuals are developing muscle memory and neural pathways (Sorgente et al., 2021).

Bearing in mind this context, the scientific background as well as the experiments from the following Chapters highlight a significant yet under-investigated potential for substantiating the efficacy, effectiveness and quickness of certain modalities as an outline for assessing, enhancing, and even prognosticating motor skills and/or performance in young populations. The emphasis on efficiency aligns with the imperative of resource optimization, acknowledging the practical constraints often faced by educators, coaches, and researchers when striving to fulfill their work. Efficiency also emerges as the guiding principle that permeates this dissertation, influencing its design and application. For instance, with the emphasis on applicability in real-world scenarios acknowledges the diverse settings in which motor skills are enforced, ranging from educational environments to athletic training. Additionally, efficiency resonates with the broader impact on practitioners (including teachers, educators, and trainers), providing them with scientific yet practical information that can be directly and rapidly replicated on-field.

Examining the intricate interplay of motor skills with broader dimensions, e.g., visuo-motor coordination and/or athletic prowess, the aim of this thesis is to present a unified framework which emphasize the pursuit of novel approaches to enhance motor skills in developing populations, i.e., children and adolescents, both for general proficiency and sporting performance, respectively. Grounded in principles such as ecological considerations, independence from laboratory settings, cost-effectiveness, and quasi-non-invasive methodologies, this framework seeks to narrow the gap between experimental research environments and practical, real-world applications. The ultimate goal is to provide professionals in the educational and sporting fields with valuable and novel insights from the scholarly community. The following Chapters are drawn from the scientific and editorial experiences of the author, which have all been pursued in first person. (Sorgente et al., 2021, 2022, 2023a; Muñoz de la Cruz et al., 2023; Sorgente et al., 2023b).

2. Crosstalk between Gross and Fine Motor Domains during Late Childhood: The Influence of Gross Motor Training on Fine Motor Performances in Primary School Children

Abstract. Gross and fine motor competence have a close relationship during development and are shown to correlate to some extent. However, the study of the interaction between these domains still requires further insights. In this study, we investigated the developmental changes in overall motor skills as well as the effects of gross motor training programs on fine motor skills in children (aged 6–11, n = 240). Fine motor skills were assessed before and after gross motor intervention using the Box and Block Test. The gross motor intervention was based on the Test of Gross Motor Development—3rd Edition. Results showed that gross and fine motor skills correlate across all years of primary school, both significantly improving with age. Finally, the gross motor intervention appeared to not influence fine motor skills. Our findings show that during primary school age, overall motor development is continuous, but non-linear. From age nine onward, there seems to be a major step-up in overall motor competence, of which teachers/educators should be aware of in order to design motor educational programs accordingly. While gross and fine motor domains might be functionally integrated to enhance children's motor performances, further research is needed to clarify the effect of gross motor practice on fine motor performances.

2.1 Introduction

Motor skills refer to the underlying internal pathways responsible for moving the body through space as well as the cognitive processes that give rise to such movements (Burton and Rodgerson, 2001). These are classically divided into two categories, namely gross motor skills and fine motor skills (Robinson, 2011). Specifically, gross motor skills involve the body's large muscles and pertain to movement of the trunk and limbs whereas fine motor skills involve the body's small muscles and pertain to movements of wrists and fingers (Cohen et al., 2018a; Bravi et al., 2019). Moreover, gross motor skills are further categorized into locomotor and object control skills (Ulrich, 2017a; Webster, Martin and Staiano, 2019).

General development of motor skills undergoes major improvements during the formative years of childhood (i.e., 5–11 years of age) due to the maturation of the central and peripheral nervous system and locomotor system (Lipkin, 2009). Research has shown that during child development, gross and fine motor competencies appear to have some correlation (Seashore, 1942; Oxendine, 1967; Roebers and Kauer, 2009; Cameron et al., 2012; Dayem, Salem and Hadidy, 2015; Oberer, Gashaj and Roebers, 2017). In fact, it was suggested that specific gross motor activities could involve fine motor adjustments (e.g., ball dribbling and handling, ball-striking with a bat, throwing at a target, skipping through a hopscotch-type pattern) (Seashore, 1942; Oxendine, 1967). Moreover, the same higher order neuromotor processes appear to be involved in the learning and mastering of both gross and fine motor skills(Roebers and Kauer, 2009). Accordingly, gross and fine motor skills have been defined as motor domains that partially share the same cognitive processes (Oberer et al., 2017).

Previous studies have investigated the relationship between gross and fine motor skills during various steps of children's school education, obtaining contentious results when comparing gross and fine individual performance measures (Cameron et al., 2012; Dayem et al., 2015; Oberer et al., 2017). For instance, Cameron et al. and Oberer et al. showed moderate correlation between gross and fine motor skills. Specifically, Oberer et al., 2017, reported a positive correlation in children aged 5.6–7.25 years, assessing both gross and fine motor skills using speed and precision tasks (e.g., jumping sideways and one leg stand for gross motor skills, posting coins, and drawing trail for fine motor skills). Similarly, Cameron and colleagues' investigation also reported a positive correlation in younger children (aged 3–4 years), assessing gross motor skills using balance, imitation, and hop and skip tasks, whereas fine motor skills were evaluated using spatial organization tasks (e.g., building a tower with bricks and drawing tasks). Furthermore, Dayem et al., 2015, showed that an even higher correlation between gross and fine motor skills occurred in children aged 4–6 years, assessing gross motor skills using stationary, locomotor, and object manipulation tasks, while fine motor skills were assessed using a writing task. Conversely, other authors disagree with the positive correlation between gross and fine motor skills (Souza et al., 2010; Tortella et al., 2016; Amaro et al., 2017). Specifically, Tortella and colleagues' study reported that there was no correlation between gross and fine motor skills in pre-school children aged 5–6 years, evaluating gross motor skills using precision, balance, throwing, and walking tasks, while fine motor skills were assessed using manual speed and precision tasks (e.g., building bricks and posting coins). Moreover, Souza et al. found that when investigating global motor performance with the Bayley Scales of Infant and Toddler Development—Third Edition, there was a clear individual variability in overall motor proficiency as well as a weak correlation between gross and fine motor skills. Finally, Amaro et al. reported no correlation between gross and fine motor skills in children aged 5–10 years when comparing the scores obtained in the "Körperkoordinationtest für kinder" and Minnesota manual dexterity test, respectively.

These contrasting results may be attributed to the fact that motor skills do not follow linear developmental trajectories (Flatters et al., 2014). Hence, it is not surprising that investigating children of different ages could produce different results. Furthermore, these studies assessed motor skills during short age spans using heterogeneous tasks. To our knowledge, a broader investigation regarding the gross-fine motor development during the entire late childhood developmental stage (i.e., primary school children) with consistent motor assessment methods has yet to be carried out.

Despite the mentioned elements of relationship during development, the influence of gross motor training on fine motor skill enhancement in school age children has not been adequately assessed in the literature. Indeed, research has mainly focused on interactions between gross-fine motor skills and other competence domains (e.g., social skills (Leonard and Hill, 2014; Dehghan et al., 2017), cognitive skills (van der Fels et al., 2015; Zeng et al., 2017), academic achievement (Fernandes et al., 2016; Aadland et al., 2017), indicating a positive influence of both gross and fine motor skills on these elements (Cameron et al., 2016; Geertsen et al., 2016). However, a specific approach aiming to explore the influence that components of gross and fine motor domains exert on each other is missing. Given that both gross and fine motor skills hold a mutual influence on these fundamental factors for children's overall well-being, it is plausible that gross and fine motor skills share some elements, which the enhancement of one (i.e., gross motor skills) could also improve the other (i.e., fine motor skills).

In the current study, we sought to expand the focus pertaining to the motor development of primary school children in two directions: first, to investigate developmental changes in overall motor skills during late childhood, which was achieved by comparing both gross motor training results as well as fine motor performances among the different ages. Second, to examine the effects of short gross motor training programs on fine motor skills in children, which was achieved by comparing the pre- and post-training results for the evaluation of fine motor skills.

2.2 Materials and Methods

2.2.1 Participants

A total of 240 typically developing male and female children from age six to 11 participated in this study. All subjects were free of any documented visual, motor, and/or neurological impairments, nor any intellectual disabilities. None of the participants were involved in extracurricular sports practice. The study protocol was approved by the institution ethics committee, Prot. N.0018234E, Rif. 63/12. Prior to the start of the study, written informed consent was obtained from the parents/legal guardians of the children. Participants were all tested individually by the principal investigator and six research assistants, all of whom were familiar with the purpose of the study. The participants' characteristics are summarized in Table 2.1.

Table 2.1. Characteristics of the participants.

Grade	Age (Years)	n	Boys	Girls	Age (Years)	
1st Grade	6–7	66	40	26	M [1] ± SD [2]	8.57 ± 2.33
2nd Grade	7–8	50	29	21	Range	6–10.6
3rd Grade	8–9	48	30	18		
4th Grade	9–10	45	27	18		
5th Grade	10–11	31	20	11		
Total		240	127	113		

[1] M = mean; [2] SD = standard deviation.

In this study, fine motor skills were evaluated using the Box and Block Test (BBT) (Jongbloed-Pereboom, Nijhuis-van der Sanden and Steenbergen, 2013), whereas gross motor skill training sessions were conducted using the Test of Gross Motor Development—Third Edition (TGMD-3) (Ulrich, 2017a). Regarding the gross motor training, the total sample of subjects was divided into three subgroups: locomotor and ball skills subgroup (LBS), which executed all the TGMD-3 skills; locomotor skills subgroup (LS), which only executed the six LS subscale skills of TGMD-3; and the ball skills subgroup (BS), which only executed the seven BS subscale skills of TGMD-3 (Table 2.2).

Table 2.2 Number of subjects per grade and subgroups of gross motor skills training.

Grade	LBS [1]	LS [2]	BS [3]
1st Grade	22	22	22
2nd Grade	17	16	17
3rd Grade	17	16	15
4th Grade	15	15	15
5th Grade	11	9	11
Total (%)	77 (32.1%)	81 (33.7%)	82 (34.1%)

[1] LBS = Locomotor and ball skills subgroup. [2] LS = Locomotor skills subgroup. [3] BS = Ball skills subgroup.

The purpose of the division was to observe whether the practice of a specific subset of skills could be more impactful on manual dexterity performance.
The reasons for dividing the sample into three groups were many, one being that gross motor skills are generally categorized into locomotor and object control (Webster et al., 2019). Furthermore, the training of different types of gross motor skills have been shown to influence other aspects related to motor performance (Westendorp et al., 2011). Moreover, short forms of the TGMD have already been conducted in the recent literature (Valentini et al., 2018; Bandeira et al., 2020) for training/assessment of just one of the two subsets of gross motor skills included in the test (i.e., locomotor or object manipulation skills).

2.2.2 Set up, Tasks, Procedure
The study spanned across five consecutive days, similar to previous studies (Oxendine, 1967; Guest et al., 2017) (Table 2.3).

Table 2.3. Timeline of the study.

Activity	FMS [1] Evaluation (Baseline)	GMS [2] Training	FMS [1] Evaluation (Post GMS [2] Training)
(Test)	BBT [3]	TGMD-3 [4]	BBT [3]
Day #	Day 1	Day 2 Day 3 Day 4	Day 5
Test time	5–10 min	30–45 min	5–10 min

[1] FMS = Fine Motor Skills; [2] GMS = Gross Motor Skills; [3] BBT = Box and Block Test; [4] TGMD-3 = Test of Gross Motor Development—Third Edition.

At the beginning of the study (i.e., day 1) each participant underwent a baseline evaluation for the fine motor skills of both the dominant and the non-dominant hand. Following that, participants took part in three gross motor skill training sessions (one session per day, i.e., days 2–4) which lasted from 30 to 45 min (Strong et al., 2005). During these sessions, the participants' gross motor skills were also evaluated. Finally, the same procedure for the evaluation of fine motor skills was also executed post-gross motor skills training (i.e., day 5). Both the fine motor skills evaluations and gross motor skills training sessions took place in indoor school gymnasiums.

The BBT is a simple, validated, and suitable test that can be administered quickly to assess fine motor skills in children from age three onward (Mathiowetz, 1985; Mathiowetz, Federman and Wiemer, 1985). The materials needed for the BBT are a wooden box (53.7 × 25.4 × 8.5 cm) divided into two compartments by a partition (15.2-cm-high) and 150 wooden cubic blocks (2.5 cm per side). We adopted the same procedure for both the fine motor skills evaluation of this study (i.e., baseline and post-gross motor skills training). Each subject was seated on a height-adjustable chair, with the forearms resting on a desk. Both hands were tested separately, starting with the dominant hand, which was determined by asking the participants to write their name on paper. All 150 cubes were placed in one compartment. The test consisted in transferring as many blocks as possible, one block at a time and with one hand, from one compartment to the other in 60 s. Each test was preceded by a 15 s practice period. The cube placement always allows for lateral to medial movements (i.e., when testing the right hand, all the 150 cubes were placed in the right compartment of the box and had to be moved to the left compartment of the box). The number of blocks transferred in 60 s was the outcome score of the test. The maximum total score possible for a single trial was 150, meaning that in 60 s, all cubes were moved from the lateral compartment to the medial compartment.

The TGMD-3 is a direct observation assessment that measures the performance of various gross motor skills in children ages 3–10.9 years (Burns et al., 2017). The continued popularity of the TGMD has been associated with its increasing use in research in child development, physical activity, and public health (Temple et al., 2016; Sgrò et al., 2017b; Duncan et al., 2018; Scheuer, Herrmann and Bund, 2019). Particularly, the latest edition of the TGMD (i.e., the TGMD-3) has been proposed as a valid and reliable assessment tool for measuring gross motor skills competence in both pre-school and primary school children (Ulrich, 2017b; Griffiths et al., 2018; Magistro et al., 2018; Rey et al., 2020).

The skills present in the TGMD-3 include a selection of fundamental gross motor skills that are commonly taught in the primary physical education curriculum on an international scale (Allen et al., 2017). Specifically, the TGMD-3 assesses 13 fundamental motor skills, partitioned into two subscales: locomotor skills and ball skills. The skills assessed in the locomotor subscale include run, gallop, one-legged hop, skip, jump, and slide. The skills assessed in the ball subscale include two-hand strike, one-hand strike, dribble, kick, catch, overhand throw, and underhand throw. Other than for motor skills assessment purposes, the TGMD has been suggested for training and improvement of specific motor skills (Wrotniak et al., 2006).

In this study, testing stations were created for each skill (Table 2.4) and the evaluations were conducted observing the TGMD-3 assessment form guidelines (Ulrich, 2017a), indicating the researcher to illustrate the proper execution of the skill, and then the subject to complete one practice trial, followed by two formal trials.

Table 2.4. Equipment needed for the TGMD-3 stations.

Locomotor Skills	**Equipment**	**Material**	**Measures**
ALL	Mini markers	Polyethylene	Base diameter 9.52 cm, height 16.51 cm
Ball Skills	**Equipment**	**Material**	**Measures**
Two hand strike	Batting tee Baseball bat	Rubber, latex free Rigid polyethylene Plastic	44.19 cm 43.69 cm 7.62 cm Diameter 7.62 cm Barrel diameter 5.72 cm, height 76.2 cm
One hand strike	Pickleball paddle Tennis ball	Plastic rubber and latex	Length 35.6 cm, plastic grid 1.3 cm Non-pressurized
Dribbling	Playground balls	Nylon and rubber	Diameter 21.59 cm
Kicking	Playground balls	Nylon and rubber	Diameter 21.59 cm
Catch	Baseball	Rigid polyethylene	Diameter 7.62 cm
Overhand throw	Tennis ball	Rubber and latex	Non-pressurized
Underhand throw	Tennis ball	Rubber and latex	Non-pressurized

Each skill was evaluated by examining 3–5 performance criteria. For instance, the gross motor skill named "dribbling" included three different criteria: make ball contact with one hand at the waist level; push (not slap) the ball with the fingertips; and maintain control for four consecutive bounces.

During the skill execution, the evaluator marked "1" in the score box for every performance criterion that the subject correctly demonstrated. If the subject did not demonstrate the appropriate criterion, a score of "0" was recorded in the score box. Total scores from the performance criteria over the two formal trials were summed to create a raw skill score. Raw skill scores were summed to provide a total raw score for either the locomotor or ball skill subscales or combined to provide a total TGMD-3 raw score. The maximum possible scores were 100 for the LBS subgroup, 46 for the LS subgroup, and 54 for the BS subgroup.

2.2.3 Handling Data

Data obtained consisted of the scores that subjects were given for the fine motor skills evaluations of day 1 (i.e., baseline) and day 5 (post gross motor training). Scores of the gross motor training were taken on day 2, day 3, and day 4. Although we collected data from gross motor training sessions, the TGMD-3 scores were only used for comparison between ages and groups, and not as a measure of gross motor proficiency.

Data were analyzed using MATLAB_R2020b software (The MathWorks, Inc., Natick, MA, USA). Nonparametric analyses were conducted since the Shapiro-Wilk test revealed a non-normal distribution of data ($p < 0.001$). In order to observe whether motor performances would differ based on sex, we conducted a Mann-Whitney U-test for independent variables comparing girls' and boys' BBT scores as well as the girls' and boys' TGMD-3 scores. Moreover, to observe whether gross and fine motor performances improve with age, we used the Spearman's rank correlation coefficient among the subjects' grades and BBT scores as well as the subjects' grades and TGMD-3 scores. For the same purpose, the Kruskal-Wallis test for independent variables was conducted using the BBT scores with grades. Similarly, potential differences in gross motor activity due to age were investigated by conducting the Kruskal-Wallis test using the TGMD-3 scores with grades. The Kruskal-Wallis test was followed by the Dunn-Bonferroni adjusted post-hoc test in the case of multiple comparisons. Furthermore, aiming to investigate whether higher fine motor skills performances are related to higher gross motor performances, we used the Spearman correlation among the subjects' scores in the BBT and TGMD-3. In addition, in order to observe whether there is a difference in fine motor skills performances before and after a short intervention of gross motor training, we conducted a Friedman test for dependent variables between BBT scores at the baseline and post-gross motor skills training.

2.3 Results

Descriptive data confronting the males' and females' BBT and TGMD-3 scores are reported in Table 2.5 and Table 2.6, respectively.

Table 2.5. Scores [1] of the BBT divided by sex (males M, females F).

Dominant Hand				**Non-Dominant Hand**			
Baseline		Post		Baseline		Post	
M	F	M	F	M	F	M	F
55 (7)	54 (7)	50.5 (9)	50 (8)	55 (8)	54 (7)	51 (9.25)	50 (8)

[1] Median (interquartile range).

Table 2.6. Scores [1] of the TGMD-3 divided by sex (males M, females F).

LBS [2] Subgroup						**LS [3] Subgroup**						**BS [4] Subgroup**					
Sessions						Sessions						Sessions					
1st		2nd		3rd		1st		2nd		3rd		1st		2nd		3rd	
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
80 (13)	81 (14)	82 (15)	81 (16)	85 (13)	82 (13)	46 (9)	44 (9)	45 (7)	42 (8.5)	46 (8)	44 (10)	38 (7.3)	36 (5)	38 (5.3)	36 (8.5)	38 (5)	37 (5.5)

[1] Median (interquartile range), [2] LBS = Locomotor and ball skills subgroup, [3] LS = Locomotor skills subgroup, [4] BS = Ball skills subgroup.

Furthermore, we explored the possibility that motor performances would differ based on sex when comparing the girls' BBT scores with the boys' BBT scores by conducting a Mann-Whitney U-test for independent variables. In a similar fashion, we also compared the girls' TGMD-3 scores with the boys' TGMD-3 scores. No significant differences were found in both the BBT and TGMD-3 scores between the boys' and girls' performances for all subgroups and across all sessions (Table 2.7 and Table 2.8).

Table 2.7. Mann-Whitney U-test between male and female BBT scores.

	Data	**Baseline**	**Post**
Dominant hand	U	7025	7188.5
	Z	0.31	0.62
	p	0.76	0.53
Non-dominant hand	U	7181	7591.5
	Z	0.61	1.40
	p	0.54	0.16

Table 2.8. Mann-Whitney U-test between male and female TGMD-3 scores.

Subgroup	**Data**	**1st Session**	**2nd Session**	**3rd Session**
LBS [1]	U	762.5	748.5	724.5
	Z	0.43	0.56	0.79
	p	0.67	0.58	0.43
LS [2]	U	618	582.5	670
	Z	1.38	1.74	0.86
	p	0.17	0.84	0.39
BS [3]	U	529.5	526.5	517
	Z	1.63	1.67	1.76
	p	0.10	0.94	0.08

[1] LBS = Locomotor and ball skills subgroup. [2] LS = Locomotor skills subgroup. [3] BS = Ball skills subgroup.

TGMD-3 scores improved with age in all subgroups (LBS, LS, and BS) across all sessions, albeit with some exceptions (Table 2.9).

Table 2.9. TGMD-3 scores [1] for all grades and all subgroups of gross motor skills training.

	LBS [2] Subgroup				**LS [3] Subgroup**				**BS [4] Subgroup**		
	Sessions				Sessions				Sessions		
Grade	1st	2nd	3rd	Grade	1st	2nd	3rd	Grade	1st	2nd	3rd
1st grade	74.5 (8.5)	75.5 (10)	78 (12.25)	1st grade	33 (6.75)	34.5 (7.5)	36 (3.25)	1st grade	40.5 (8.5)	39.5 (8.25)	40 (7.5)
2nd grade	75 (12.5)	75 (16)	77 (15.5)	2nd grade	36 (4.25)	37.5 (8.75)	37 (6.75)	2nd grade	45 (11.5)	45 (9)	43 (10)
3rd grade	82 (11.5)	82 (12.5)	84 (11.5)	3rd grade	37 (3.75)	38 (4.75)	37.5 (5.75)	3rd grade	45 (8)	44 (7)	45 (6)
4th grade	87 (11)	86 (9)	87 (9)	4th grade	38 (8)	40 (5)	39 (7)	4th grade	47 (6)	45 (3)	48 (6)
5th grade	87 (9)	90 (9)	91 (10)	5th grade	39 (5)	40 (5)	38 (3.5)	5th grade	51 (5)	51 (3)	50 (2)

[1] Median (interquartile range), [2] LBS = Locomotor and ball skills subgroup, [3] LS = Locomotor skills subgroup, [4] BS = Ball skills subgroup.

In order to investigate the relationship of gross motor skills with age, we compared the subjects' grade with TGMD-3 scores using the Spearman's rank correlation coefficient. Correlation between grades and TGMD-3 scores were found to be low to moderate and significant for all of the three gross motor training sessions, ranging from $R = 0.33$ to 0.59, $p < 0.001$, except for the LS subgroup in the 3rd session with $p < 0.05$ (Table 2.10).

Table 2.10. Spearman's rank correlation coefficient between TGMD-3 scores and grades.

Subgroup	**1st Session**	**2nd Session**	**3rd Session**
LBS [1]	$R = 0.52$ $p < 0.001$	$R = 0.59$ $p < 0.001$	$R = 0.53$ $p < 0.001$

Subgroup	1st Session	2nd Session	3rd Session
LS [2]	R = 0.39 p < 0.001	R = 0.42 p < 0.001	R = 0.33 p < 0.001
BS [3]	R = 0.55 p < 0.001	R = 0.50 p < 0.001	R = 0.54 p < 0.001

[1] LBS = Locomotor and ball skills subgroup, [2] LS = Locomotor skills subgroup, [3] BS = Ball skills subgroup.

Moreover, in order to evaluate possible differences in gross motor skills due to age, we compared the subjects' TGMD-3 scores with grades by conducting the Kruskal-Wallis test for independent variables, followed by the Dunn-Bonferroni adjusted post-hoc test for multiple comparison. The analysis returned mixed results among the different sessions for LBS, LS, and BS subgroups, as significant differences were found between grades in all subgroups and sessions, except for the LS subgroup in the third session (Table 2.11).

Table 2.11. Kruskal-Wallis test followed by the Dunn-Bonferroni post-hoc between TGMD-3 scores and grades.

Subgroup	Data	1st Session	2nd Session	3rd Session
LBS [1]	Chi Sq	33.53	29.84	24.00
	d.f. [4]	4	4	4
	p	<0.001	<0.001	<0.001
	Post-hoc [5]	1 vs.4; 1 vs.5; 2 vs.4; 2 vs.5	1 vs.4; 1 vs.5; 2 vs.4; 2 vs.5	1 vs.4; 1 vs.5; 2 vs.4; 2 vs.5
LS [2]	Chi Sq	13.41	13.53	8.94
	d.f. [4]	4	4	4
	p	<0.05	<0.05	=0.06
	Post-hoc [5]	1 vs.5	1 vs.4; 1 vs.5	//
BS [3]	Chi Sq	26.8	27.89	26.69

Subgroup	Data	1st Session	2nd Session	3rd Session
	d.f. [4]	4	4	4
	p	<0.001	<0.001	<0.001
	Post-hoc [5]	1 vs.4; 1 vs.5; 2 vs.5	1 vs.5; 2 vs.5; 3 vs.5; 4 vs.5	1 vs.4; 1 vs.5; 2 vs.5

[1] LBS = Locomotor and ball skills subgroup. [2] LS = Locomotor skills subgroup. [3] BS = Ball skills subgroup. [4] d.f. = degrees of freedom. [5] Refers to the significant difference ($p < 0.05$) between the single grades.

BBT scores improved with age for the dominant and the non-dominant hand both for the baseline and the post-gross motor skills training assessments (Table 2.12).

Table 2.12. BBT scores[1] comparison between the baseline and post-gross motor skills training assessments.

	Dominant Hand		**Non-Dominant Hand**	
Grade	Baseline	Post	Baseline	Post
1st grade	50 (3)	52 (2)	45 (2)	46 (1)
2nd grade	53 (2)	54 (2)	49.5 (2.25)	50 (2.25)
3rd grade	56 (1.75)	57 (2.25)	53.5 (3)	54 (2)
4th grade	57 (2)	59 (3)	54 (3)	55 (2)
5th grade	62 (3)	63 (4)	56 (3)	57 (3)

[1] Median (interquartile range).

In order to investigate the relationship of fine motor skills with age, we compared the subjects' grade with BBT scores using the Spearman's rank correlation coefficient. Specifically, the correlation between grade and BBT scores was found to be high and significant for the baseline assessment for both the dominant and non-dominant hand. The same was also found for the post-TGMD-3 assessment (Table 2.13).

Table 2.13. Spearman's rank correlation coefficient between BBT scores and grades.

Dominant Hand		Non-Dominant Hand	
Baseline	Post	Baseline	Post
R = 0.95 p < 0.001	R = 0.94 p < 0.001	R = 0.94 p < 0.001	R = 0.92 p < 0.001

Moreover, in order to evaluate possible differences in fine motor skills due to age, we compared the subjects' BBT scores with grades by conducting the Kruskal-Wallis test for independent variables, followed by the Dunn-Bonferroni adjusted post-hoc test for multiple comparison. The analysis showed significant differences for the BBT scores among grades, both in the dominant hand and non-dominant hand (Table 2.14).

Table 2.14. Kruskal-Wallis test followed by the Dunn-Bonferroni post-hoc between BBT scores and grades.

	Data	Baseline	Post
Dominant hand	Chi Sq	206.8	203.48
	d.f. [1]	4	4
	p	<0.001	<0.001
	Post-hoc exceptions [2]	3 vs.4; 4 vs.5	3 vs.4; 4 vs.5
Non-dominant hand	Chi Sq	203.48	200.48
	d.f. [1]	4	4
	p	<0.001	<0.001
	Post-hoc exceptions [2]	3 vs.4; 4 vs.5	3 vs.4; 4 vs.5

[1] d.f. = degrees of freedom. [2] Refers to the non-significant differences ($p > 0.05$) between single grades.

All comparisons were found to be statistically significant (both dominant and non-dominant hand with $p < 0.001$) except for the 3rd vs. 4th grade ($p = 0.11$ in the dominant hand, $p = 0.30$ in non-dominant hand) and the 4th vs. 5th grade ($p = 0.10$ in the dominant hand, $p = 0.72$ in non-dominant hand). As for the post TGMD-3 assessment, results were similar, as significant differences were found for the BBT scores among grades, both in the dominant

hand and non-dominant hand. All comparisons were found to be statistically significant (both dominant and non-dominant hand with $p < 0.001$) except for the 3rd vs. 4th grade ($p = 0.18$ in the dominant hand, $p = 0.27$ in non-dominant hand) and the 4th vs. 5th grade ($p = 0.17$ in the dominant hand, $p = 0.11$ in the non-dominant hand).
In order to investigate the relationship between fine gross and fine motor skills, the Spearman correlation was implemented on the subjects' BBT and TGMD-3 scores (Table 2.15).

Table 2.15. Spearman correlation between BBT scores and TGMD-3 scores.

		LBS [1]		
BBT Evaluations		1st Session	2nd Session	3rd Session
Baseline	Dominant hand	R = 0.56 p < 0.001	R = 0.56 p < 0.001	R = 0.50 p < 0.001
	Non-dominant hand	R = 0.58 p < 0.001	R = 0.57 p < 0.001	R = 0.53 p < 0.001
Post	Dominant hand	R = 0.57 p < 0.001	R = 0.55 p < 0.001	R = 0.48 p < 0.001
	Non-dominant hand	R = 0.62 p < 0.001	R = 0.61 p < 0.001	R = 0.56 p < 0.001
		LS [2]		
Baseline	Dominant hand	R = 0.39 p < 0.001	R = 0.40 p < 0.001	R = 0.33 p < 0.05
	Non-dominant hand	R = 0.33 p < 0.05	R = 0.38 p < 0.001	R = 0.24 p < 0.05
Post	Dominant hand	R = 0.40 p < 0.001	R = 0.43 p < 0.001	R = 0.36 p < 0.05
	Non-dominant hand	R = 0.36 p < 0.05	R=0.40 p < 0.001	R = 0.27 p < 0.05
		BS [3]		

LBS [1]				
BBT Evaluations		1st Session	2nd Session	3rd Session
Baseline	Dominant hand	R = 0.55 p < 0.001	R = 0.51 p < 0.001	R = 0.57 p < 0.001
	Non-dominant hand	R = 0.54 p < 0.001	R = 0.47 p < 0.001	R = 0.50 p < 0.001
Post	Dominant hand	R = 0.56 p < 0.001	R = 0.51 p < 0.001	R = 0.55 p < 0.001
	Non-dominant hand	R = 0.48 p < 0.001	R = 0.40 p < 0.001	R = 0.45 p < 0.001

[1] LBS = Locomotor and ball skills subgroup. [2] LS = Locomotor skills subgroup. [3] BS = Ball skills subgroup.

As for the LBS subgroup, results showed a statistically significant low to moderate correlation between the BBT and TGMD-3 scores (ranging from $R = 0.48$ to 0.62, $p < 0.001$). Regarding the LS subgroup, the correlation between the BBT and TGMD-3 scores were found to be low (ranging from $R = 0.24$ to 0.40), though statistically significant for all sessions ($p < 0.05$). Concerning the BS subgroup, the analysis indicated similar results to the LBS subgroup, thus a significant low to moderate correlation between the BBT and TGMD-3 scores (ranging from $R = 0.40$ to 0.57, $p < 0.001$).

Furthermore, both gross and fine motor skills seemed to improve as sessions progressed, with the exception of the 5th grade (Figure 2.1).

In order to investigate potential differences in gross motor skills due to the training intervention, the Friedman test was implemented on the TGMD-3 scores for all sessions (i.e., between the 1st and 2nd session, the 2nd and 3rd session, and the 1st and 3rd session). Though TGMD-3 scores seemed to improve as the sessions progressed (Figure 2.1), none of the changes among the sessions of gross motor training were found to be statistically significant (Table 2.16).

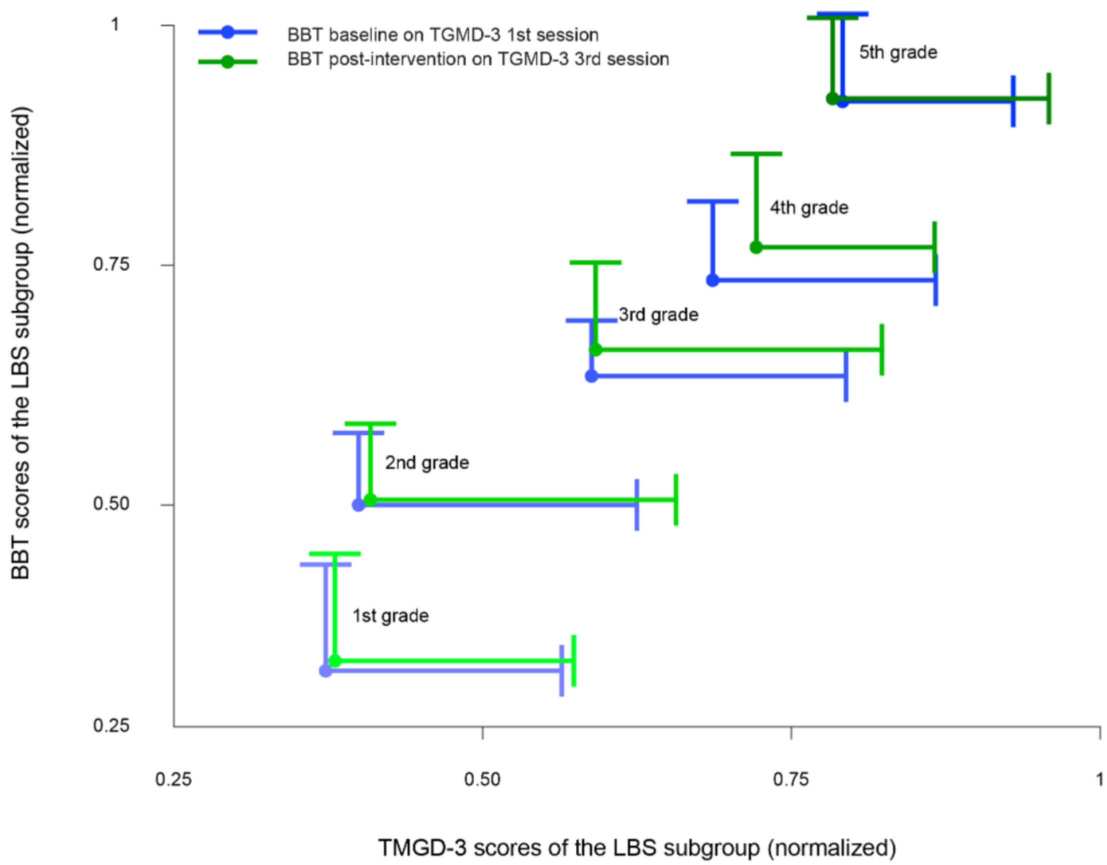

Figure 2.1. Results for gross and fine motor proficiency for the LBS subgroup. The scores are reported as a normalized mean of the BBT and the TGMD-3 per grade (dots) and standard deviations (lines). Performances gradually improved with age for both gross and fine motor skills, but this overall improvement was more evident between the 1st and 4th grade, 1st and 5th grade, 2nd and 4th grade, and 2nd and 5th grade, as evidenced by the significant difference ($p < 0.001$) in general motor proficiency (see Table 2.11 and Table 2.14). Conversely, no significant differences were found in both gross and fine motor performances as the sessions progressed (see Table 2.16 and Table 2.17).

Table 2.16. Statistical significance (p-value) of the changes in gross motor performance during the intervention.

LBS [1] Subgroup				**LS [2] Subgroup**				**BS [3] Subgroup**			
Sessions				Sessions				Sessions			
Grade	1st vs. 2nd	2nd vs. 3rd	1st vs. 3rd	Grade	1st vs. 2nd	2nd vs. 3rd	1st vs. 3rd	Grade	1st vs. 2nd	2nd vs.3rd	1st vs. 3rd
1st grade	p = 0.16	p = 0.82	p = 0.06	1st grade	p = 0.08	p = 0.13	p = 0.65	1st grade	p = 0.52	p = 0.28	p = 0.15
2nd grade	p = 0.24	p = 0.25	p = 0.36	2nd grade	p = 0.19	p = 0.91	p = 0.31	2nd grade	p = 0.38	p = 0.77	p = 0.82

	LBS [1] Subgroup				LS [2] Subgroup				BS [3] Subgroup		
	Sessions				Sessions				Sessions		
Grade	1st vs. 2nd	2nd vs. 3rd	1st vs. 3rd	Grade	1st vs. 2nd	2nd vs. 3rd	1st vs. 3rd	Grade	1st vs. 2nd	2nd vs.3rd	1st vs. 3rd
3rd grade	p = 0.31	p = 0.69	p = 0.45	3rd grade	p = 0.11	p = 0.72	p = 0.59	3rd grade	p = 0.26	p = 0.54	p = 0.69
4th grade	p = 0.22	p = 0.18	p = 0.34	4th grade	p = 0.85	p = 0.45	p = 0.53	4th grade	p = 0.96	p = 0.39	p = 0.14
5th grade	p = 0.09	p = 0.45	p = 0.21	5th grade	p = 0.68	p = 0.78	p = 0.56	5th grade	p = 0.17	p = 0.16	p = 0.33

[1] LBS = Locomotor and ball skills subgroup, [2] LS = Locomotor skills subgroup, [3] BS = Ball skills subgroup.

In order to investigate potential differences in fine motor performance due to gross motor training intervention, the Friedman test was implemented on the BBT scores before and after the TGMD-3 sessions (i.e., baseline and post-TGMD-3 training). Though BBT scores seemed to generally improve from baseline to post-TGMD-3 intervention (Figure 2.1), no significant results were found for both the dominant hand and non-dominant hand (Table 2.17).

Table 2.17. Friedman's test between BBT scores at the baseline and BBT scores post gross motor skills training.

	Dominant Hand			Non-Dominant Hand		
Grade	**p-Value**	**Chi-Sq**	**d.f.** [1]	**p-Value**	**Chi-Sq**	**d.f.**
1st grade	0.43	0.68	1	0.74	0.63	1
2nd grade	0.11	0.50	1	0.88	0.41	1
3rd grade	0.24	0.86	1	0.66	0.74	1
4th grade	0.09	0.25	1	0.13	0.13	1
5th grade	0.08	0.19	1	0.25	0.36	1

[1] d.f. = degrees of freedom.

2.4 Discussion

The purpose of the present study was to expand the focus pertaining to motor development during primary school age, at the same time investigating the influence of different short gross motor training on fine motor performance. The results showed a general improvement for both gross and fine motor performances with age (Table 2.9 and Table 2.12). Moreover, our findings confirm previous observations (Cameron et al., 2012; Oberer et al., 2017) showing a moderate to high correlation between gross and fine motor skills (Table 2.15). However, neither the improvements nor declines in a single grade performances were found to be significant ($p < 0.05$) throughout the experiment for both gross (Table 2.16) and fine motor performances (Table 2.17). Regarding the gross motor intervention, it is worth mentioning that we used the same test battery to train and assess the exact same skills during the experiment, which could result in a training effect of the specific skills. However, as the scope of the gross motor measurement was to investigate developmental changes (i.e., older children tend to perform better than younger ones with a continuous but non-linear trend), our experimental design did not intend to evaluate changes in gross motor performance across the intervention. Furthermore, it was possible to observe some differences in the developmental path among the three subgroups of gross motor training. Specifically, the LBS and BS subgroup presented consistent differences ($p < 0.001$) between children aged 6–8 and 9–11, while the LS subgroup presented less consistent differences over gross motor sessions between children aged 6–7 and 10–11 (Table 2.11). Concerning the influence of gross motor practice on fine motor skills, no differences in fine motor performances were found following the gross motor practice program (Table 2.17). Regarding sex-related motor performance, no differences were found between male and female performances for both gross and fine motor skills (Table 2.7 and Table 2.8).

In this study, both gross and fine motor skills significantly improved with age (Table 2.11 and Table 2.14). This trend was expected as competency in fundamental movement skills has been shown to follow an increasing developmental trajectory, with both gross and fine motor skills improving with chronological age (McKenzie et al., 2002; Okely, Booth and Chey, 2004; Williams et al., 2008). Moreover, Bolger et al. already observed that in primary school children, older children scored significantly higher than their younger peers in both locomotor and object-control scores in the TGMD-2 (Bolger et al., 2018). Therefore, in relation to the current literature and our findings, it seems that during primary school years, children's gross and fine motor competence continuously improve with age (see Table 2.11 and Table 2.14 and Figure 2.1).

As was observed, as gross and fine motor skills follow different developmental paths (Haibach, Collier and Reid, 2011), it is not surprising that we found the age-fine motor skills correlation to be higher than the age-gross motor skills correlation (Table 2.10 and Table 2.13). Moreover, fine motor performances did not differ between the 3rd and 4th grade and between the 4th and 5th grade (i.e., between children aged 9–10 and aged 10–11), although significant differences were found between the 3rd and 5th grade (i.e., between children aged 9 and 11, see Table 2.14). A possible explanation for this trend is that children aged 9–11 experience a period of stabilization in the physical growth and consolidation of both cognitive and neuro-motor abilities (Rosenbloom, 1994; Albuquerque et al., 2021). However, it should be mentioned that while for fine motor skills evaluation we used a single task test (i.e., the BBT), for gross motor assessment, we used a test battery of diversified tasks (i.e., the TGMD-3). As the scope of this paper was to provide a general evaluation of the effect of different types of gross motor training on fine motor performance, we limited the fine motor skills evaluation to a single test (widely used in the literature (Strong et al., 2005; Jongbloed-Pereboom et al., 2013)). As gross motor control is generally considered as a sum of different subsets of skills (Webster et al., 2019), it is fitting to use different tasks when designing an overall gross motor training intervention. On the other hand, fine motor control is not classically defined by different subsets of skills and was used in this study as an output measure. Furthermore, other studies have already compared a different number of tasks between gross and fine motor training tests (Cameron et al., 2012; Dayem et al., 2015; Tortella et al., 2016; Oberer et al., 2017). Nonetheless, it is possible that the lower correlation and heterogeneity of results we found in the gross motor assessment among grades could be due to the higher request of motor variability (Eldred and Darrah, 2010). Certainly, a different combination of gross and fine motor skills assessments could provide different results. However, this would go beyond the scope of this paper. Future studies should clarify the aspects related to the influence of different combination of gross and fine motor skills assessments on overall motor performance.

As for the relationship between gross and fine motor skills, high scores on gross motor skills assessment reflected high scores in fine motor skills evaluation across all the sessions of this study and for all the gross motor activity subgroups. These results are in line with the research work of Oberer et al., which suggested a moderate level of relationship between gross and fine motor skills (Oberer et al., 2017). In addition, Cameron et al. already indicated that children with higher scores in fine motor skills evaluations tended to score higher on the gross motor assessments compared to children with lower scores in gross or fine motor assessments (Cameron et al., 2012). However, it is worth noting that while both studies were conducted on kindergarten children, this study expanded the scope of the gross-fine motor relationship to the primary school years. Therefore, including the primary educational stage to the topic of gross–fine motor relationship, this study contributed to further explore the features of overall motor development across all years of childhood.

Although we found a correlation between gross and fine motor skills, this cannot be attributed to a direct influence of the gross motor training used in this study on fine motor performance. This apparent lack of influence may suggest that the designed gross motor training intervention was not adequate for influencing fine motor skills in the short-term, regardless of the type of gross motor activity. The intervention duration might be a critical point (i.e., three sessions of gross motor practice to influence fine motor performance). In this regard, although some studies have also shown that a short-term intervention could influence motor performances (Cohen et al., 2018b; Bandeira et al., 2020), the general notion is that short-term intervention would not elicit great changes in performances (Lai et al., 2014; Cohen et al., 2014). Thus, it is not surprising that the gross motor training in this study did not bring significant differences in fine motor performance. The results support the notion of a certain critical point for intervention duration. Hence, more training time may be needed to observe a significant influence of gross motor training on fine motor skills.

Another doubtful element could be related to the design of the gross motor training program. Seeing that in this study we used three different motor training programs composed of numerous tasks (i.e., the TGMD-3 locomotor skills battery, ball skills battery, and the complete battery), it might be appropriate to focus on a reduced number of tasks for efficiently stimulating gross motor skills. As previously mentioned, this would reduce the demand for motor variability, allowing subjects to perform a more specific training that would return less heterogeneous results than those present in this study. Though the training used in this study was relatively task specific, it has been widely used in the literature for the assessment of general gross motor proficiency (Ulrich, 2017b; Burns et al., 2017; Griffiths et al., 2018). However, future studies will benefit from the examination of developmentally focused training as well as neutral training programs. Moreover, having found no differences in the type of gross motor training carried out, we would suggest future research to keep investigating the influence of both locomotor and object manipulation training on fine motor performance.

The topic of motor skills differences between male and female children appears to be contentious in the research literature. As for this study, no differences were found between male and female motor performances (Table 2.7 and Table 2.8). These results are in line with various research work that suggested that there are no sex differences in fine motor skills in primary school children (Blank et al., 1999; Cohen et al., 2021). In addition, Slykerman et al. indicated that there may be no sex differences in the locomotor skills in children with a mean age of 6.5 years (Slykerman et al., 2016). However, other studies suggest otherwise. For instance, when assessing gross motor skills in school age children, Bolger et al. found that boys scored significantly higher than girls in the object-control score while girls scored significantly higher in the locomotor score (Bolger et al., 2018). For ages 7–8, it has been noted that boys develop ball skills earlier than girls and that girls acquire fine motor skills before boys (Junaid and Fellowes, 2006). Based on the results of this study and on recent literature, our cautious position is that when considering the whole late childhood development stage, there may be no clear differentiation between males and females in overall motor performances. However, these aspects should be investigated with further and dedicated research.

2.5 Conclusions

The study of interactions between gross and fine motor skills is important for identifying novel strategies to enhance motor learning during childhood. This research expands current findings regarding the relationship between gross and fine motor skills to the late childhood developmental stage. Moreover, our results align with previous findings regarding the positive correlation between gross and fine motor skills. Although we did not observe a short-term influence of gross motor practice on fine motor control, it is possible that longer interventions could provide a more prominent effect on fine motor performances. Thus, designing other types of interventions could be useful to deepen the interaction between the gross and fine motor domains during the children’s school years. Finally, this study showed that overall motor development appears to follow a specific trajectory in primary school subjects. In particular, both males and females aged 9–11 seem to experience a major step-up in both gross and fine motor proficiency compared to their younger peers (ages 6–8). Other than an academic audience, these findings are also valuable for teachers, educators, and trainers (i.e., professionals who design and put into practice children’s motor educational programs). Further studies are needed to better clarify the relationship between gross and fine motor proficiency during different stages of primary school education.

3. The Best of Two Different Visual Instructions in Improving Precision Ball-Throwing and Standing Long Jump Performances in Primary School Children

Abstract. Two observational learning approaches have been shown to be successful in improving children's motor performances: one is "technique-focused", another is "goal-focused". In this study, we sought to compare the effectiveness of these two strategies, thus testing for the more efficient method of observational learning to enhance motor skills in primary school children. To this end, two experiments were designed. Experiment 1 involved a precision ball throwing task. Experiment 2 involved a standing long jump task. A total of 792 subjects (aged 6–11) participated in this study and were divided into technique-focus (Experiment 1 n = 200; Experiment 2 n = 66), goal-focus (Experiment 1 n = 195; Experiment 2 n = 68), and control groups (Experiment 1 n = 199; Experiment 2 n = 64). The experiments were divided into pretest, practice, and retention phases. During the practice phase, the technique-focus and goal-focus groups were given different visual instructions on how to perform the task. The results showed that children aged 10–11 belonging to the technique-focus group performed significantly better in the practice phase than both the goal-focus and the control group ($p < 0.001$), but only for the precision ball throwing task. These findings could be useful for training adaptation in the context of motor learning and skills acquisition.

3.1 Introduction

The use of visual cues and instructions has been shown to be beneficial for enhancing motor performances (Karlin and Mortimer, 1962; Hebert, 2018; van der Loo, Krahmer and van Amelsvoort, 2021). In particular, visual instructions serve an important role in motor learning, encouraging the acquisition of motor skills without the time-consuming process of trial-and-error learning (Bekkering, Wohlschläger and Gattis, 2000; Hebert, 2018). Furthermore, visual instructions allow the learner to construct a mental representation of the desired performance, break the whole task into subcomponents, select essential information, and configurate appropriate strategies to reconstruct the task, ultimately leading to a more efficient performance (Kitsantas, Zimmerman and Cleary, 2000; Wulf et al., 2010a). In this regard, the process of learning a task by watching someone else performing this task is defined as observational learning (van der Loo et al., 2021). Observing a model serves an important function in human motor development, as the learner benefits from the activation of a matching motor program by direct perceptual-motor mapping (Bekkering et al., 2000; Hebert, 2018). Visual instructions in the form of observational learning are generally found to be more effective than doing nothing (Wulf, Shea and Lewthwaite, 2010b) or than verbal instructions alone (Williams and Ford, 2008; De Stefani et al., 2020) in leading to optimal motor performance. However, during the process of motor learning, the amount of information provided to the learner should be carefully balanced. Indeed, too much information could negatively influence motor performances (Guadagnoli and Lee, 2004; Lee et al., 2016; Schmidt et al., 2019), especially in children, since they are considered to be novice performers on account of their lack of experience, unfamiliarity with skills, and low motor repertoire (Fathi Khatab, Ghasemi and Mousavi Sadati, 2018). Consequently, in order to maximize each learning session, a fragmented approach of observational learning could prove to be useful, allowing the learner to focus specifically on a single aspect of the performance. In fact, it was shown that motor performances tend to improve when a few simple, easy-to-follow instructions are provided (Wulf et al., 2010b; Popp et al., 2020). The question with a fragmented and reduced approach for motor skill acquisition is: In order to achieve better performances faster, which information is more relevant and thus more efficient?

To this end, there seems to be two principal lines of thought pertaining the optimization of the “learning by observing” process. The first is focusing the visual instructions on the final effector of the movement (i.e., a “goal-focused” visual instruction), whereas the second is focusing the visual instructions on the proper movement technique (i.e., a “technique-focused” visual instruction). For instance, several authors (Hayes, Ashford and Bennett, 2008; Catmur and Heyes, 2019) stated that what the learner extracts from observing a model’s movement is the sole desired goal of the action, not the motor command or the kinematic primitives. Conversely, other research has shown that instructions that were related to the movement technique enhanced body cognition, motor performance, and motor learning compared to instructions that were not technique-related (Wulf et al., 2000; Agar et al., 2016; Benjaminse et al., 2018). Instead, Krajenbrink et al., 2018, and van der Loo et al. 2021, argued that, ultimately, motor learning is allowed by the experience the subject undergoes during the process of repeated practice, regardless of the nature of the instructions. Though these approaches have their own merits, a direct comparison between the “technique-focus” and the “goal-focus” fragmented strategies of observational learning is still lacking. Moreover, despite the fact that typically developing children represent an important population for motor learning research, recent studies examining the effects of observational learning on motor performance have been predominantly conducted in children with autism spectrum disorder, using a wide variety of tasks including computer gaming (MacDonald and Ahearn, 2015), building a house with a set of bricks (Foti et al., 2019), peer-yoked contingency gaming (Luke and Singh, 2018), labelling pictures, and opening a box with a plastic stick (Nadel et al., 2011).

Bearing in mind the significant role ascribed to adequate motor competence as a determinant of public health (Lloyd et al., 2014), social skills (Ohara et al., 2019), cognitive skills (Veldman, Okely and Jones, 2015), and academic achievement (Escolano-Pérez, Herrero-Nivela and Losada, 2020), a crucial goal for scholars, educators, and teachers should be to understand and promote the strategies that facilitate motor skills learning and performance during childhood (Sorgente et al., 2021). Considering this past research, in the present study, we sought to determine the best of two observational learning methods to improve children's motor performances. Specifically, we tested the more efficient approach between the technique-focused (i.e., how to prepare the task) and the goal-focused (i.e., how to execute the task) visual instructions in enhancing motor skills across late childhood during the execution of two complex motor tasks, such as the Precision Ball Throwing (PBT) and the Standing Long Jump (SLJ). In particular, the PBT has been defined as an object manipulation task (Ulrich, 2017b), which requires mainly upper limbs and eye–hand coordination, whereas the SLJ has been defined as a locomotor task (Ulrich, 2017b), which requires mainly lower limb coordination as well as strength/power elements. Since these two tasks represent different facets of motor performance, comparing the effectiveness of two observational learning strategies for different motor tasks allows a global overview in regard to efficient motor skills learning. Finally, previous studies have shown that from age 10 onwards, there is a major step-up in motor competence when assessing either fine motor skills, object manipulation skills, or locomotor skills (McKenzie et al., 2002; Okely et al., 2004; Bolger et al., 2018). This would be attributed to the fact that children of these ages experience a period of stabilization in physical growth and consolidation of both cognitive as well as neuromotor abilities (Albuquerque et al., 2021; Cohen et al., 2021). Therefore, it would be plausible to expect a significant increase in motor performances for both the PBT and SLJ tasks from age 10 onwards.

3.2 Materials and Methods

3.2.1 Participants

The study was composed of two experiments, which are described in the specific sections below. Additionally, the minimum number of participants required for the experiments was determined by an a priori power analysis using G*Power, estimating a sample size of 165 subjects ($f = 0.5$, alpha at 0.05, with 95% power for ANOVA repeated measures within factors). Nevertheless, additional subjects were recruited in order to ensure a normal distribution of the data. Following Experiment 1, it was apparent that there was no additional benefit of a superfluous number of subjects. Therefore, we modulated the number of participants recruited for Experiment 2 accordingly.

A total of 792 subjects took part in the study. Specifically, 594 children participated in Experiment 1 (involving the PBT), while a total of 198 children participated in Experiment 2 (involving the SLJ) (Table 3.1).

Table 3.1. Number of participants per age and experiment.

Age (Years)	n (PBT [1])	n (SLJ [2])	n (PBT [1] + SLJ [2])
6	99	31	130
7	102	36	138
8	102	33	135
9	97	33	130
10	96	35	131
11	98	30	128
Total	594	198	792
M [3] ± SD [4]	8.5 ± 1.87		

[1] PBT = Precision Ball Throwing; [2] SLJ = Standing Long Jump; [3] M = mean; [4] SD = standard deviation.

All of the participants were 6 to 11 years old and reported no known physical or intellectual deficits. None of the participants were involved in extracurricular sports practice in the last six months. The study protocol was approved by the Institutional Ethics Committee of Comitato Etico Area Vasta Centro AOUCareggi, Prot. N.0018234E, Rif. 63/12. Furthermore, all children provided assent and the parents/guardians provided informed consent. All of the participants were unfamiliar with the experimental tasks and were all tested individually by the principal investigator and one research assistant, who was familiar with the purpose of the study.

3.2.2 Set up, Tasks, Procedure

With regard to the PBT task (used in Experiment 1), several studies have assessed movement effectiveness by using outcome measures, such as accuracy in hitting a target throwing balls/darts (for a review, see (Wulf et al., 2010b)). Concerning the SLJ task (used in Experiment 2), this has been suggested as one of the most valid field-based methods to assess various facets of motor development, such as muscular strength and gross motor coordination (Gontarev et al., 2014; Hraski, Hraski and Prskalo, 2015). Being part of a large number of international batteries, the SLJ has been suggested as a practical, time efficient, and cheap method of assessing muscular fitness in children (Wu et al., 2003). Since the optimal execution of these two tasks requires different neuromotor abilities (Haywood Kathleen M. & Getchell, 2005), this experimental design permits observation of the effect of visual instructions on motor learning from a multifaceted standpoint, rather than investigating a single aspect of motor learning (i.e., investigating only a precision task or a gross motor task).

The experiments were performed in a large, quiet room, where only the principal investigator and a research assistant were available. There was no time limit for any of the conditions, as participants performed at their preferred speed (Southard, 2011). For both experiments, each participant was randomly assigned to one of three groups, i.e., technique-focus, goal-focus, or control group (Table 3.2).

Table 3.2. Number of subjects per age and experimental conditions.

	PBT [1]			**SLJ [2]**		
Age (Years)	T [3]	G [4]	C [5]	T [3]	G [4]	C [5]
6	32	33	34	9	12	10
7	36	34	32	12	11	13
8	35	33	34	10	13	10
9	34	30	33	14	10	9
10	30	31	35	10	13	12

	PBT [1]			SLJ [2]		
Age (Years)	T [3]	G [4]	C [5]	T [3]	G [4]	C [5]
11	33	34	31	11	9	10
Total	200	195	199	66	68	64

[1] PBT = Precision Ball Throwing; [2] SLJ = Standing Long Jump; [3] T = technique-focus group; [4] G = goal-focus group; [5] C = control group.

The technique-focus group was given visual instructions regarding how to efficiently prepare the execution of the task, whereas the goal-focus group was given visual instructions showing the final execution of the task. The control group did not receive any visual or verbal instruction throughout the experiment. Moreover, for each participant, the experiment spanned across two consecutive days, and consisted of three different phases, i.e., pretest, practice, and retention phases (Table 3.3).

Table 3.3. Timeline of the experiment.

Experimental Phase	**Pretest**	**Practice**	**Retention**
Activity	Baseline evaluation of the task	Visual instruction stimulation before performing the task	Re-perform the task with no further visual instructions
Day #	Day 1	Day 1	Day 2
Number of trials	PBT [1] = 5 SLJ [2] = 2	PBT [1] = 7 × 3 [3] SLJ [2] = 2	PBT [1] = 7 × 3 [3] SLJ [2] = 2

[1] PBT = Precision Ball Throwing; [2] SLJ = Standing Long Jump; [3] 7 × 3 = seven blocks of three ball-throws.

Prior to the pretest phase, the principal investigator briefly explained the task to the subject. During the pretests, no specific verbal/visual instructions nor feedback were given. Shortly after the pretest phase, the practice phase was conducted. During the practice phase, two different pre-recorded video demonstrations of the motor skill were presented on an electronic tablet: one for the goal-focus group, and another for the technique-focus group. The model who appeared in the videos was skilled at performing the task (Wulf et al., 2010a).

We opted for a pre-recorded video demonstration in order to ensure consistency during administration (Palmer et al., 2017); previous research supports this method for visually demonstrating skills (Olivier et al., 2008), as it was shown that children's performance does not change when given a video demonstration in lieu of a live demonstration (Palmer et al., 2017). Since it has been suggested that children may be overwhelmed with different types of information (Wulf et al., 2010a), the videos contained no audio instructions. The control group did not watch any video demonstration, as participants were asked to perform the task with no other instructions provided. One day after the pretest and practice phases, the retention phase was conducted. During the retention phase, the participants were asked to perform the task again, as many times as in the practice phase. Moreover, in the retention phase, no further instructions or reminders were given for any of the groups.

3.2.2.1 Experiment 1: Precision Ball Throwing

The task was to throw polyethylene low density balls (1 cm in diameter) at a polypropylene circular target, which was 38 cm in diameter. The target had three concentric rings, each 3 cm in width, and a 3-cm-diameter bullseye in the center. The target's surface was covered with felt, while each ball had Velcro (i.e., hook and loop strips) attached to its surface. Thanks to this setup, with each throw, the ball stuck to the target, allowing the subjects to observe the result of their shot. The bullseye's height and distance were adjusted according to age (Emanuel, Jarus and Bart, 2008). Specifically, the target height for all groups was 1.22 m; the target distance for younger children (age 6–8) was 1.50 m, whereas the distance for older children (age 9–11) was 2.00 m. To indicate the distances, two white tapes were placed at 1.50 m and 2.00 m from the target. The PBT task required participants to throw the balls aiming at the bullseye. The participants always threw with their dominant hand, which was determined by asking the participants to write their name on paper (Jongbloed-Pereboom et al., 2013). The participants' PBT performances were scored in the following way: balls that hit the bullseye were given 3 points; balls that hit the innermost ring (i.e., the ring right outside of the bullseye) were given 2 points; and balls that hit the outermost ring were given 1 point. Balls that missed the target were given 0 points. Seeing that Emanuel et al., 2008, reported that the children were distracted by the balls they had already thrown and often asked to remove them from the target, in this study, the research assistant removed the ball after every single trial performed. The assistant made sure not to interfere with the visual field of the participants during the trials.

For the pretest phase, the participants performed five ball throws (Wulf et al., 2000), for a possible maximum total score of 15. After the pretest, in the practice phase, the visual instruction stimulations were presented. For the technique-focus group, the video showed the optimal movement technique for performing the PBT task (i.e., feet and hand placement, stance, and ball grip), whereas for the goal-focus group, the video showed only the final movement execution of the PBT task (i.e., ball throw and arm follow-through). Each video lasted approximately 30 s. The optimal technique regarding the PBT task was adapted from the research work of Kitsantas et al., 2000, and van der Loo et al., 2021, and is reported in Table 3.4.

Table 3.4. Based on the group (technique-focus or goal-focus), different subcomponents of the PBT performance were shown in the video demonstrations.

Technique-Focus Group	Goal-Focus Group
Grip: Holding the ball between the first and second finger and the thumb	Throw: Only the forearm and wrist are used to throw the ball
Stance: The right foot is slightly ahead of the left foot	Follow-through: After releasing the ball, allow the arm to continue its natural motion

One day after the pretest and practice phases, the retention phase was conducted. On the retention tests, the target was placed at the same distance that was used during the practice [8]. For both the practice and retention phases, the participants completed seven blocks of three ball throws [58], for a possible maximum total score of 63.

3.2.2.2 Experiment 2: Standing Long Jump

The SLJ task required the participants to jump horizontally from a standing still position, moving their body as far as possible in a forward direction (Sgrò et al., 2017a). The performance in the SLJ was evaluated by the total jump distance, which is the horizontal distance from the take-off line to the mark made by the heel on landing and was measured in centimeters with a tape measure (Gontarev et al., 2014). The take-off line was evidenced by a tape on the floor. No steps backward or preparatory hops/runs were allowed.

After the pretest phase (consisting of two attempts), for the practice phase, the visual instruction stimulations were presented to both the technique-focus and goal-focus groups. For the technique-focus group, the video showed the optimal movement technique for performing the SLJ task (i.e., stance and take-off angle reaching), whereas for the goal-focus group, the video showed only the final movement execution of the SLJ task (i.e., the horizontal jump and landing). The control group participants did not watch any video demonstration. Each video lasted approximately 30 s. The optimal technique regarding the SLJ performance was taken from Hraski et al., 2015 and is reported in Table 3.5. One day after the pretest and practice phases, the retention phase was conducted. The participants performed two attempts of the SLJ for each phase of the experiment.

Table 3.5. Based on the group (technique-focus or goal-focus), different subcomponents of the SLJ performance were shown in the video demonstrations.

Technique-Focus Group	Goal-Focus Group
Stance: The feet are shoulder-width apart	Horizontal jump: Jump as far as possible while extending the arms, hips, and legs
Take-off angle reaching: Squat while forward shifting the bodyweight, bending the knees at 90 degrees. While squatting, the arms go forward	Landing: the arms sweep forward and down to the hips. The feet are extended out until hitting the ground. The knees and hips absorb the impact as the body continues to move forward

3.2.3 Handling Data

The data consisted of the scores that subjects were given for the experimental task (i.e., the PBT or the SLJ task). Specifically, each subject was given three scores, one for each experimental phase (i.e., pretest, practice, and retention). Regarding the PBT task, the performance score was obtained by summing all of the scores for the single trials, while regarding the SLJ task, the performances were scored by registering the longest jump distance.

The data were analyzed using IBM SPSS Statistics 26 software. Parametric analyses were conducted, as the Shapiro–Wilk test revealed a normal distribution of data ($p = 0.000$). First, in order to test whether the sample of subjects was homogeneous regarding motor performances, a two-way ANOVA was implemented to evaluate the differences in performance scores, both between ages (i.e., factor 1: 6, 7, 8, 9, 10, and 11 years of age) and between groups (i.e., factor 2: technique-focus, goal-focus, and control). Moreover, a mixed ANOVA was implemented to evaluate the differences in performance scores among two between-subjects factors (i.e., ages and groups) and one within-subjects factor (i.e., time, referring to the practice and retention phases). Both the two-way ANOVA and the mixed ANOVA were followed by the Bonferroni post hoc test for multiple comparisons.

3.3 Results

3.3.1 Experiment 1: Precision Ball Throwing

The results for the PBT scores are reported in Table 3.6.

Table 3.6. PBT performance scores [1] per age, group, and experimental phase.

	T [2]			G [3]			C [4]		
Age	**Pre [5]**	**Pract. [6]**	**Ret. [7]**	**Pre [5]**	**Pract. [6]**	**Ret. [7]**	**Pre [5]**	**Pract. [6]**	**Ret. [7]**
6	9.5 (1)	30 (2)	29 (2.25)	9 (2.25)	29 (1)	29 (2.75)	8 (2)	30 (1.25)	28 (2)
7	10 (1.25)	31 (2.50)	30 (2)	9 (3)	31 (1.75)	30 (2.75)	9 (2)	31 (2)	29 (3)
8	10 (3)	32 (2)	32 (3.25)	9.5 (3)	32 (1)	32 (2)	10 (3)	32 (3)	32 (2)
9	10.5 (2)	34 (2.75)	33 (3)	10 (3.25)	33 (3)	34 (3)	9.5 (3)	33 (2)	34 (3)
10	10 (2)	52 (3)	42 (1)	10 (2)	42.5 (2.75)	42 (2.25)	10 (2.75)	42 (3)	43 (3)
11	12 (3)	55 (4)	43 (3)	11 (3)	44 (2)	44 (3)	11 (3)	44 (3.5)	43 (3)

[1] Median (interquartile range); [2] T = technique-focus group; [3] G = goal-focus group; [4] C = control group; [5] Pre = pretest phase; [6] Pract. = practice phase; [7] Ret. = retention phase.

For the pretest phase, the two-way ANOVA of the PBT performances for the factors group and age showed that there was no significant effect of experimental conditions on the PBT scores ($F (10, 591) = 1.92$, $p = 0.14$), meaning that the sample of subjects had the same starting level of motor skills. However, there was a significant effect of age on the PBT scores for all experimental conditions ($F (5, 591) = 14.65$, $p < 0.001$). Thus, as expected, the subjects' motor performances tended to improve with age. In particular, the Bonferroni post hoc test for multiple comparisons showed a significant difference ($p < 0.001$) in PBT performances among all ages (6 vs. 7, 6 vs. 8, 6 vs. 9, and so forth). Furthermore, the mixed ANOVA showed that there was a significant interaction effect of age, experimental condition, and time on the PBT performances ($F (10, 591) = 72.01$, p = < 0.001). Specifically for the practice phase, we found that the mean score of the PBT for the technique group (mean = 39.16, standard deviation = 10.70) was significantly different ($p < 0.001$) than both the goal-focus (mean = 35.43, standard deviation = 4.38) and control groups (mean = 34.39, standard deviation = 5.83). This would denote that right after the visual instruction stimulation, the technique-focus group performed significantly better compared to the goal-focus and control groups. Interestingly, the Bonferroni post hoc test for multiple comparisons revealed that this significant difference in PBT scores among groups (p <

0.001) was present only for ages 10 and 11, whereas there were no group differences in PBT performances among the subjects aged 6–9 years (Figure 3.1).

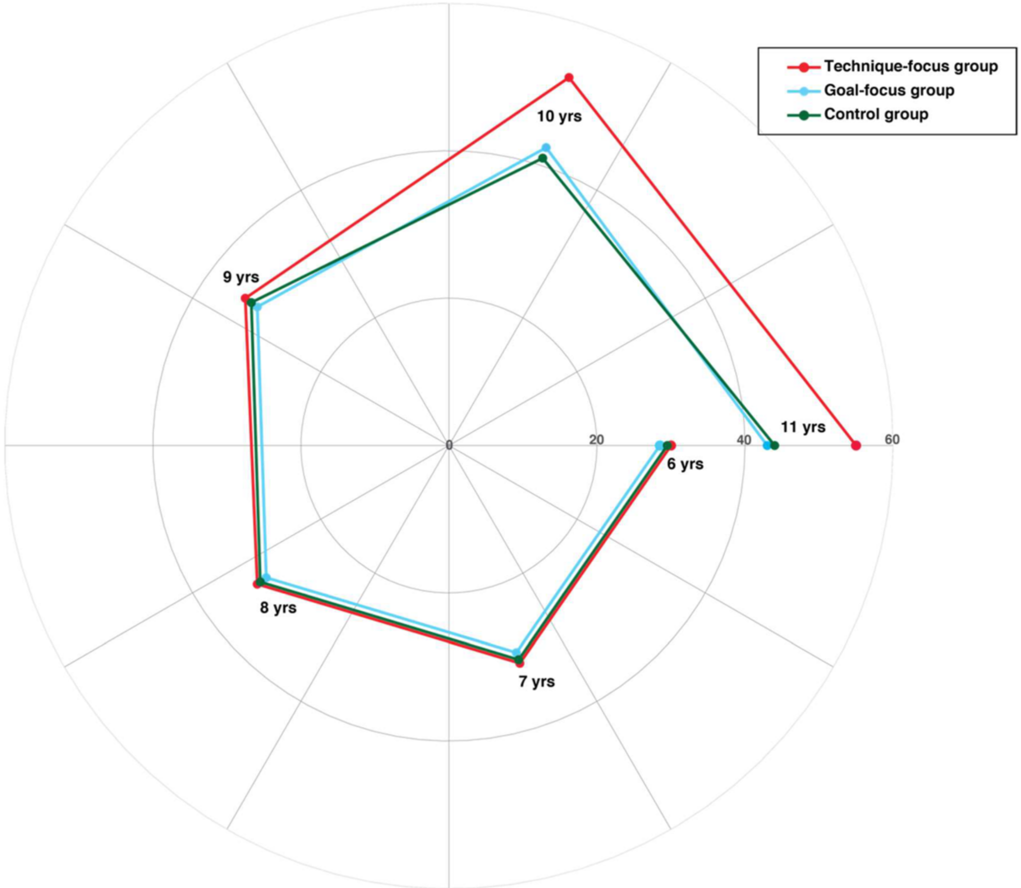

Figure 3.1. Polar diagram showing the mean scores obtained by all subjects for the PBT task during the practice phase. It is worth noting that while from age 6 to 9, the PBT scores were almost the same for all groups, subjects aged 10 and 11 of the technique-focus group (red line) performed the PBT task significantly better ($p < 0.001$) than both the goal-focus (cyan line) and control groups (green line).

However, for the retention phase, this effect was seemingly lost, as during this phase, the mean PBT performances for the technique-focus group (mean = 35.14, standard deviation = 6.08) did not significantly differ ($p = 1.00$) from the goal-focus (mean = 36.23, standard deviation = 5.10) and control groups (mean = 35.20, standard deviation = 5.98).
Moreover, the mean PBT score for the technique-group at the practice phase (mean = 39.16, standard deviation = 10.70) was significantly different ($p < 0.001$) from the mean PBT score of the same group at the retention phase (mean = 35.14, standard deviation = 6.08). This was not the case for the goal-focus and control groups, whose mean PBT scores did not significantly differ from the practice phase to the retention phase.

3.3.2 Experiment 2: Standing Long Jump

The descriptive statistics for the SLJ scores are reported in Table 3.7.

Table 3.7. SLJ performance scores [1] per age, group, and experimental phase.

	T [2]			G [3]			C [4]		
Age	**Pre [5]**	**Pract. [6]**	**Ret. [7]**	**Pre [5]**	**Pract. [6]**	**Ret. [7]**	**Pre [5]**	**Pract. [6]**	**Ret. [7]**
6	103.2 (3)	103.1 (2.55)	102.9 (3.60)	103.2 (3.75)	103.8 (2.50)	102.9 (2.90)	102.9 (2.25)	102.8 (3.18)	103.2 (3.75)
7	108.5 (4.21)	107.3 (4)	109.3 (5.60)	107.2 (4.08)	107.9 (3.81)	110.8 (2.61)	109.6 (3.20)	108.4 (4.22)	108.5 (4.20)
8	115.8 (5.50)	118.7 (3.75)	119 (7.20)	119 (5.45)	114.9 (4.15)	116 (3.40)	117.5 (3.60)	114.5 (7.70)	117.2 (7.80)
9	121.6 (7)	121.5 (4.1)	123 (8)	123.4 (5.32)	122.9 (10.22)	122.47 (6.46)	122.3 (3)	122 (8.5)	122.5 (7)
10	130 (4.70)	129.3 (5.62)	124 (6.34)	130.1 (7.97)	127 (5.50)	126.5 (8.81)	125 (7.47)	130.1 (8.34)	129.8 (4.56)
11	138 (3.81)	136.2 (3.55)	134.8 (2.76)	134 (2.17)	136 (4.92)	136.45 (5.15)	136.5 (4.06)	135.6 (3.37)	136.2 (3.95)

[1] Median (interquartile range); [2] T = technique-focus group; [3] G = goal-focus group; [4] C = control group; [5] Pre = pretest phase; [6] Pract. = practice phase; [7] Ret. = retention phase.

For the pretest phase, the two-way ANOVA of the SLJ performances for the factors group and age showed no significant effect of the experimental conditions on the SLJ scores ($F(2, 195) = 1.82$, $p = 0.16$), though there was an expected significant effect of age on the SLJ scores ($F(5, 195) = 58.56$, $p < 0.001$) among all experimental conditions. In particular, the Bonferroni post hoc test for multiple comparisons showed a significant difference ($p < 0.001$) in PBT performances among all ages (6 vs. 7, 6 vs. 8, 6 vs. 9, and so forth).

Surprisingly, the mixed ANOVA returned no significant interaction effect of age, experimental condition, or time on the SLJ performances ($F(10, 195) = 0.78$, $p = 0.65$). Nonetheless, the test of the between-subjects effect showed that there was a significant effect of age on the SLJ performances ($F(5, 195) = 891.86$, $p < 0.001$), but this was not the case for the between-subjects factor or the within-subjects factor ($F(2, 195) = 1.46$, $p = 0.24$ and

F (1, 195) = 0.17, p = 0.68, respectively). Hence, conversely to what we found for an object manipulation task like the PBT, for a locomotor task like the SLJ, there seems to be no performance enhancing effect of the two visual stimulations used in this experiment (Figure 3.2).

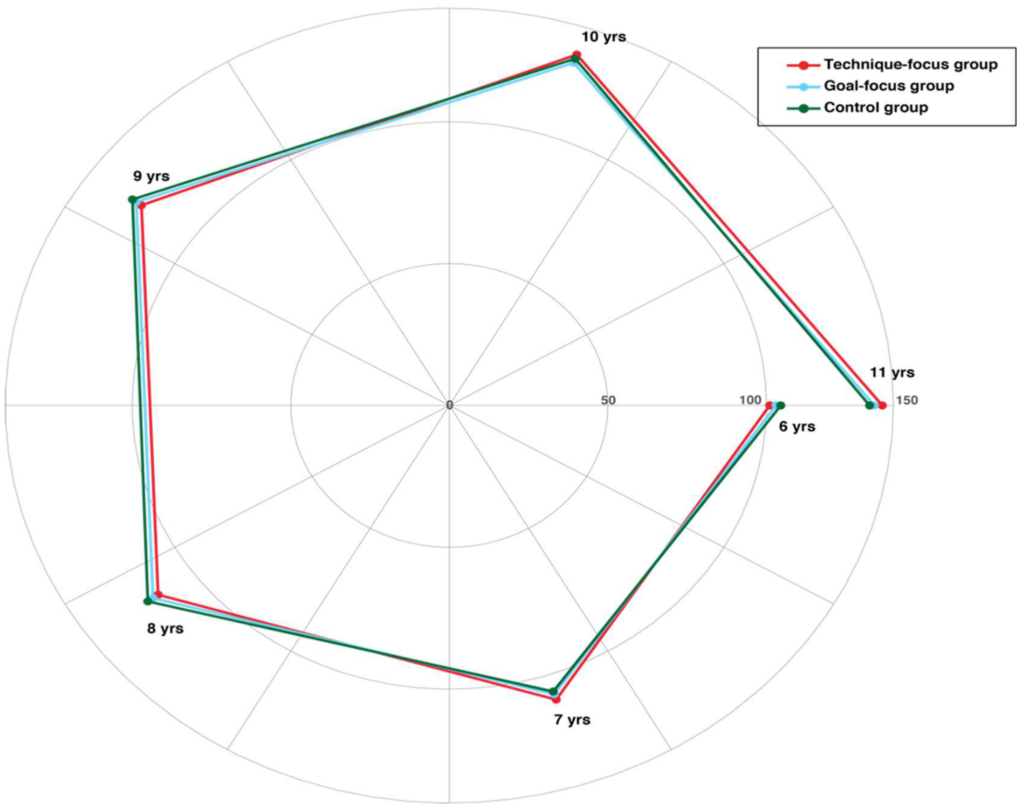

Figure 3.2. Polar diagram showing the mean scores obtained by all subjects for the SLJ task during the practice phase. Unlike the results from Experiment 1 using the PBT task, for Experiment 2, there was no significant difference in the SLJ performances (p = 0.24) among the technique-focus (red line), goal-focus (cyan line) and control (green line) groups.

3.4 Discussion

The purpose of the present study, composed of two experiments, was to compare the effectiveness of two different strategies based on observational learning for improving motor performance in primary school children. One strategy was technique-focused, i.e., the subjects observed how to optimally prepare a motor task, with no further visual information regarding the 'next steps' of said movement. Conversely, the other strategy was goal-focused, i.e., the subjects observed the actual execution of the same motor task, with no previous visual information regarding the task 'preparation'.

The results showed significant improvements of motor performance with age. Regarding Experiment 1, our findings showed that during the practice phase, the children of the technique-focus group aged 10–11 performed the PBT task significantly better than both the goal-focus and the control groups, whereas there were no significant differences among the experimental conditions for subjects aged 6 to 9 years old. Nevertheless, there was no retention of this apparent training effect brought by the technique-focused visual instruction. Concerning Experiment 2, we found no significant effect of experimental conditions on the SLJ performances, neither for the practice nor for the retention phases. Therefore, the results from this study are partially in line with previous investigations conducted on children with autism, which supported the use of observational learning strategies for enhancing motor performances (Nadel et al., 2011; MacDonald and Ahearn, 2015; Foti et al., 2019). Furthermore, our findings partly confirm that children aged 10–11 can efficiently use their short-term memory of action observation and can refine their performances without prior motor experience of certain complex motor tasks (Foti et al., 2019; De Stefani et al., 2020).

For both experiments, the motor performances significantly improved with age. This trend was expected, as competency in fundamental movement skills has been shown to follow an increasing developmental trajectory, with overall motor skills improving with chronological age (Williams et al., 2008; Bolger et al., 2018).

Regarding the comparison of effectiveness between the two observational learning approaches, the results from Experiment 1 show that when it comes to efficiently enhancing children's motor performance with visual instructions, a fragmented, technique-focused approach could be the most efficient. These outcomes are in line with previous research that has shown that instructions related to the movement technique enhanced motor performance in both children (Agar et al., 2016) and adults (Wulf et al., 2000). Seeing that these studies were conducted using verbal instructions, our study further elaborates on the topic of how to enhance children's motor skills with the use of visual instructions. Interestingly, within the technique-focus group, only children aged 10–11 experienced a step-up in motor competence regarding the PBT performances. A reason for having found a significant training effect of the technique-focus condition on PBT performances may be due to more valuable information being extracted by the subjects from observing an efficient movement technique compared to the goal-focused approach, which focused solely on the movement execution. Seeing that a focus on movement technique effectively stimulates changes in posture for biomechanical efficiency, also allowing for the optimal use of physical capabilities including accuracy in a throwing task (for a review, see Holfelder and Schott, 2014), the movement pattern recreated by observing technique-focused visual instructions seems to be of significant use for improving the motor performances in children aged 10–11. In this regard, it is likely that subjects aged 10–11 may respond better to observational learning stimulations than their younger peers, based on the notion that children from age 10 onwards experience a period of stabilization in physical growth as well as maturation of both their cognitive and neuromotor capacities (Albuquerque et al., 2021; Cohen et al., 2021), thus being more capable of choosing primary information and configurating apt plans of action to reconstruct the task, eventually leading to better motor performances. However, another consequent takeaway of this finding is that other strategies should be pursued for improving motor skills in younger children, rather than a fragmented visual approach. Concerning this aspect, children aged 6–9 years old are considered to be quite far from having matured and efficient cognitive and neuromotor systems (Fathi Khatab et al., 2018); hence, they may need more information or different strategies for motor-enhancing purposes, e.g., involving verbal instructions, complete visual instructions, or a combination of the two, as well as providing visual/verbal feedback during motor performances.

Despite a partial training effect being found for the technique-focused condition on PBT performances for children aged 10–11 years old, the same effect was not maintained during the retention phase, as we observed two key findings. First, for the retention phase, there were no significant differences in PBT performance among the experimental conditions (i.e., technique-focus, goal-focus, control). Second, the retention performances of the technique-focus group were significantly less proficient compared to the performance scores obtained during the practice phase. Given that children are regarded as novice performers concerning motor skills acquisition (Fathi Khatab et al., 2018), they may need an extended amount of practice in order to elicit any beneficial effects on their motor performance. Furthermore, retention was only tested in the short term, i.e., one day following the practice phase. Therefore, further studies are needed to learn more about the effect of observational learning strategies on long-term practice and the long-term retention of motor skills.

Moreover, while in Experiment 1 we found that a training effect was produced only by technique-focused visual instructions (though transient and only for subjects 10–11 years old), in Experiment 2, neither the technique-focused nor the goal-focused visual instructions produced a training effect on the subjects' motor performances. First, it is worth mentioning that we took advantage of the "two-experiment" design to compare the improvements in motor performances between the two different facets of motor skills, i.e., object manipulation and locomotor skills. This was done in order to evaluate this experimental design from an overall standpoint in regard to motor skills. We certainly did not expect a complete ineffectiveness of the two observational learning strategies we shaped for improving the SLJ performances. Nonetheless, these contrasting results may be due to various reasons (Guadagnoli and Lee, 2004; Lloyd et al., 2014), as well as some prominent physical constraints due to the participants' age. Specifically, while performing an object manipulation task (i.e., the PBT) mainly requires motor coordination of the dominant upper limb, performing a locomotor task (i.e., the SLJ) requires a completely different set of motor abilities, i.e., generating as much power as possible from mainly the lower limbs, along with coordinating the upper limbs and stabilizing the trunk. Hence, these neuromotor demands of strength and power may be too much of a physical constraint for primary school children, and consequently, there may be less room for technique-related approaches in non-developed individuals. Moreover, as Krajenbrink and colleagues already pointed out, one day of practice may be too short for training a complex gross motor task (Krajenbrink et al., 2018). Therefore, as we already indicated for children 6–9 years old practicing the PBT task, more training time may be needed to induce and observe significant improvements for a locomotor task like the SLJ in primary school children. Finally, a viable option for future studies could be to measure hypothetical improvements in other aspects of locomotor skills performances rather than just the score of the task, e.g., biomechanical/kinematic parameters, perception of the motor performance, as well as including technique-related scores.

3.5 Conclusions

In response to the aim of this study, the more efficient approach of observational learning between the technique-focused and the goal-focused strategies seems to be the technique-focused one. However, in light of our results, this would be a partial and short-sighted response. In fact, other aspects are worth mentioning for future research to be carefully designed. Specifically, with this experimental design, a technique-focused strategy of observational learning can enhance children's motor performances under specific conditions: if the children are at least 10–11 years old (not younger); right after the visual stimulation is provided (there seems to be no retention effect); and for a task that does not involve elements of strength/power, i.e., a precision task. Overall, the present study provides new insights into the best strategies for improving motor skills in primary school children. Moreover, our results have implications for all practical settings that involve motor performance and learning during childhood. Further studies are needed to shed more light on the influence that different approaches based on observational learning may have for improving motor proficiency during different stages of primary school education.

4. The effectiveness of adjusting resistance training loads through velocity-based techniques in youth experienced sprinters: a case series study

Abstract. This study aimed to determine if adjusting the loads via velocity-based training (VBT) in each session is more efficient in monitoring the relative intensity than programming loads assessing 1RM pre-training. To achieve this, six national level sprinters were randomly divided into two groups, i.e., adjusting loads (AL, n = 3) and not adjusting loads (NAL, n = 3), during twelve sessions of a squat training (ST) program. During this training intervention, the AL group adjusted the intensity for each session in the squat exercise depending on the speed the load was lifted after warmup. The NAL group, instead, progressed in the squat exercise referring to the 1RM estimated at pre-test. In addition, Parallel Squat (PSQ), Countermovement Jump (CMJ), Squat Jump (SJ), 30 m sprint standing start (30S) and 30 m sprint flying start (30F) tests were carried out before and after conducting the ST program. Interestingly, AL performed the ST near their estimated velocities at 70%—75% 1RM, however with a wider gap at 80%—85% 1RM. The NAL group, instead, did not presented such a detectable behavior across the whole ST. Moreover, both groups demonstrated improved performances in PSQ, CMJ, and SJ, whereas there were little changes in 30S and 30F after ST. Additionally, AL obtained a greater effect size than NAL in PSQ (0.60 vs. 0.35) but lower effect size in CMJ, SJ, 30S, and 30F (0.41 vs. 0.63, 0.30 vs. 0.40, 0.04 vs. 0.28 and 0.22 vs. 0.24). However, percentage change was greater in AL in all tests. Based on these findings, we can conclude that further investigation into the AL strategy in VBT is warranted for sprinter athletes' daily strength practices. The AL technique shows promise as a valuable tool for accurately adjusting and monitoring medium-high training loads to ensure they align with the intended intensity.

4.1 Introduction

Resistance training (RT) is commonly used for improving athletic performance in sprinters (Haugen, McGhie and Ettema, 2019). In particular, sprinters need to develop three key determinants: power, technique and sprint-specific endurance, as RT plays a paramount role in enhancing these neuromotor abilities (Moore, 2016; Haugen et al., 2019). Traditionally, the intensity during RT has mainly been prescribed using the percentage of one repetition maximum (%1RM), known as percentage-based-training (PBT) (Thompson et al., 2020).

With the %1RM approach, however, it is not possible to maintain the relative intensity (the movement execution velocity) throughout the RT session, e.g., from the first to the last set of an exercise. This is due to accumulated neuromuscular fatigue, associated overload, and possible muscle failure, eventually leading to an abrupt cessation of the set (González-Badillo and Sánchez-Medina, 2010). In addition, the actual 1RM of an athlete can fluctuate in a relatively short time because of several intrinsic and extrinsic factors (González-Badillo and Sánchez-Medina, 2010). Research have also strongly advised against frequently testing 1RM to solve this issue, seeing that there are many feasibility complications with this practice, especially across multiple lifts (Pareja-Blanco et al., 2017).

To overcome these critical aspects, an alternative methodology known as velocity-based training (VBT) has been developed (Rodríguez-Rosell et al., 2020; Pelland et al., 2022; Zhang et al., 2022). VBT consists in monitoring the speed at which the load is lifted using a linear position transducer (LPT) and then estimating the 1RM (González-Badillo and Sánchez-Medina, 2010). This is possible thanks to the relationship between load and velocity, where the higher the load, the lower the execution velocity. In this regard, it has been shown that each strength exercise has specific 1RM lifting speeds, e.g., the 1RM of a full squat would be at a speed of 0.32 m per seconds, although this may vary slightly between individuals (Sánchez-Medina et al., 2017). Therefore, this technique allows measuring the daily readiness and the decrease of velocity which represents the accumulation of fatigue, being less susceptible to changes than the %1RM method. Moreover, VBT has shown greater effects on improving high-speed actions such as sprinting or countermovement jump (CMJ), compared to traditional RT like circuit training (Dorrell, Smith and Gee, 2020; Banyard et al., 2021). In fact, a systematic review about this approach concluded that VBT could be recommended as a useful tool in terms of obtaining instantaneous objective feedback, as it provides velocity data during the training (Włodarczyk et al., 2021). Although VBT is increasingly used in research and by athletes' coaches (Suchomel et al., 2018), there is a research gap in the way in which we can monitor the daily relative intensity through velocity of execution and efficiently account for the daily changes in the athletes' performance capabilities. In fact, there is currently no evidence to support whether adjusting loads and monitoring intensity during RT programs improves power/velocity abilities in trained sprinters, who usually combine strength training with their track training, compared to not adjusting loads each session. To this matter, while it has been shown that adjusting loads according to speed performances produces no greater improvement than not adjusting the load in full squat after 8 weeks of training (Jiménez-Reyes et al., 2021), there are some critical aspects about this approach, i.e., not considering relative volume (measured by percentage of velocity loss) as they programmed establishing the same sets and repetitions for all participants. The population tested should be taken into account as they were students with RT experience and not highly trained athletes.

With these considerations in mind, in this case-series study we sought to compare the effectiveness of two VBT approaches in monitoring relative intensity across 6 weeks (twelve sessions) of squat training (ST) intervention in a group of six highly trained sprinters. In particular, one VBT strategy consisted in adjusting the load for each of the ST session, whereas the other one consisted in establishing the 1RM load at pre-test and conducting a traditional load progression accordingly. In addition, we sought to compare the effects of these VBT strategies in improving fundamental aspects of athletic performance, testing for markers of maximal strength and jumping pre- and post-ST, such as parallel squat (PSQ), countermovement jump (CMJ), squat jump (SJ), 30 m sprint standing start (30S) and 30 m sprint flying start (30F). Ultimately, this study would contribute to the existing body of knowledge with preliminary insights about which kind of VBT to use when striving to enhance the competitive form of track and field practitioners.

4.2 Materials and Methods

4.2.1 Participants

Six track and field sprinters from the same training group were included in this study. All participants were Caucasian male from the regional team of Castilla La Mancha (Spain) (Age 20 ± 1 years; body mass 70.2 ± 3.2 kg, leg length 78.3 ± 3.1 cm and height 175.9 ± 5.7 cm) with a mean of 844.2 ± 88.6 points in their best discipline according to the World Athletics Federation scoring tables, considering both outdoor and indoor times. Hence, they were classified as level 3: Highly trained/National according to McKay et al., 2022. The subjects had experience with the squat exercise and more generally in resistance training. They had more than 5 years of resistance training experience and had competed in sprint events for more than 5 years as well. However, they had never trained with exerting the highest possible speed as training goal and they were not in their life's peak of performance as normally sprinters achieve it at an age of 25–27 (Haugen et al., 2018). The participants were divided into two groups, adjusting load (AL, n = 3) and not-adjusting load (NAL, n = 3). The study design followed the ethical principles for medical research involving human participants set by the World Medical Association Declaration of Helsinki and was approved by the local ethics committee. Furthermore, participants were provided with written instructions outlining the procedures and risks associated with the study and gave informed written consent.

4.2.2 Setup, Tasks, Procedures

The experiment was conducted over a duration of 9 weeks. Prior to the pre-tests, the participants underwent a 1-week familiarization period with Velocity-Based Training (VBT). During this period, they engaged in two brief sessions where they practiced lifting light loads in the squat exercise with the goal of lifting them as quickly as possible. This familiarization phase aimed to acclimate the participants to the VBT technique. Then, two pre-test sessions were carried out. In particular, performances in PSQ, CMJ, SJ, 30F, and 30S were assessed. In the first pre-test session, participants performed CMJ and PSQ respectively. During the second pre-test session, performances in SJ, 30S, and 30F tests were evaluated. After the pre-test, the ST intervention was conducted. The ST consisted in 6 weeks (two sessions per week) of the same programme for both groups. However, the programme differed in how the load was managed during each session. That is, in the AL group, the daily squat load was readjusted from the velocity performed during the 1RM pre-test. This readjustment was performed at the end of the warmup phase (Jiménez-Reyes et al., 2021). Regarding the NAL group, the squat load was measured at the baseline and the load progression was designed accordingly, thus without further adjustments. Finally, post-test evaluations were conducted in the same manner as the pre-test phase.

The independent variable in this research was the relative intensity, indicated by the exercise execution velocity measured in m/s for each session according to previous studies (Jiménez-Reyes et al., 2021). The experimental design is further illustrated in Table 4.1.

Table 4.1. Experimental design of the study.

<table>
<tr><th>Phase</th><th>Familiarization</th><th colspan="2">Pre-test</th><th colspan="4">Squat training*</th><th colspan="2">Post-test</th></tr>
<tr><td rowspan="2">Activity</td><td rowspan="2">VBT, light loads</td><td rowspan="2">PSQ; CMJ</td><td rowspan="2">SJ; 30S; 30F</td><td>70%</td><td>75%</td><td>80%</td><td>85%</td><td rowspan="2">PSQ; CMJ</td><td rowspan="2">SJ; 30S; 30F</td></tr>
<tr><td colspan="4">3 sets until 15% in VL
4’ rest between sets</td></tr>
<tr><td>Sessions</td><td>2</td><td>1</td><td>1</td><td>3</td><td>3</td><td>3</td><td>3</td><td>1</td><td>1</td></tr>
</table>

Duration	One week	One week (two sessions)	Six weeks (twelve sessions)	One week (two sessions)

Legend: VBT = Velocity based training; PSQ = Parallel squat (kg); CMJ = counter movement jump (cm); SJ = squat jump (kg); 30S = thirty meters standing start (s); 30F = thirty meters flying start (s). VL = velocity loss; * = Training loads referring to the 1RM%.

To measure the velocity in the ST, the LPT (Chronojump; Boscosystem, Barcelona, Spain) was employed.

During the ST, both groups warmed up performing the squat exercise with submaximal loads, i.e., one set with 40% 1RM and one set with 60% 1RM, evaluated using the LPT. The set was finished when we detected 15% in VL. After 5 min of rest from this warmup sets, we proceeded with the squat velocity evaluation. Specifically, subjects performed two repetitions with the programmed load estimated at pre-test. Regarding the AL group, if performed velocity differed more than 0.05 m·s−1 from the programmed one, the training load for the subsequent ST was readjusted of ±5 Kg.

The squat training programme consisted of 12 sessions across 6 weeks (two sessions per week). In terms of intensity training progression, participants started performing 70% of estimated 1RM and incremented by 5% every three sessions until 85% estimated 1RM. All sessions consisted in 3 sets of squats recovering 4' between sets. Participants performed the set at the maximal intentional velocity. The set was stopped when two consecutive repetitions were performed at a velocity slower than 15% from the fastest repetition, which was generally the first or second repetitions of the set. This means we did not considered repetitions to monitor volume. All strength sessions were supervised by a strength and conditioning coach and co-author of this article. Apart from ST, participants performed their usual track and field sessions, supervised by their coach, as they were preparing the indoor season. Nevertheless, they were not in a competition period, thus workouts were general and the same for all of them.

In order to avoid fatigue and metabolic stress produced during the regular track and field workouts, the ST was always conducted at least 8 h before.

The protocols adopted for CMJ, PSQ, and SJ were those proposed by (Bachero-Mena, Pareja-Blanco and González-Badillo, 2021), whereas the protocols for 30S and 30F were adapted from (Loturco et al., 2015). Regarding CMJ, 10 submaximal jumps were performed to warm up. After 1 min of rest, 3 maximal jumps were then carried out recovering 1 min. The average height (cm) of these three jumps was considered for analyses purposes. Jump height was measured using Optojump (Microgate, Bolzano, Italy). PSQ incremental test consisted of lifting incremental loads from 20 Kg and adding 10 Kg until an execution velocity of 0.45 m·s−1 when the test ended. Three repetitions per load were conducted when the velocity was higher than 1.15 m·s−1, when the movement velocity was slower than 0.7 m·s−1 two repetitions were performed and when it was slower than 0.5 m·s−1 the participants only lifted the weight once per set. The velocity in the PSQ incremental test was measured through a linear encoder (Chronojump, Boscosystem, Barcelona, Spain). Moreover, we employed the PSQ incremental test to develop the force-velocity profile of each participant. By leveraging on the well-known load-velocity relation (which is $R2 > 0.98$) (SAMOZINO et al., 2012; Sorgente et al., 2023a), from the force-velocity profile we were able to establish the load intensity for each ST session. At least six loads were needed, which represent points in the linear relationship As for the SJ test, participants started the exercise with only their bodyweight, progressively increasing the load by 5-10 Kg until they jumped as low as 20 cm, which represents the optimum mean propulsive power of the athlete (Loturco et al., 2015). Participants carried out two repetitions per load (we considered the highest for posterior analyses) and recovered 3 min between sets. As in CMJ test, jump height was measure using Optojump system (Microgate, Italy, Bolzano). Finally, the 30S and 30F tests were performed twice (two sets), recovering 3 min between sets, and considering the best sprint time of each respective test for subsequent analyses. Sprints were conducted in the same athletics track for each test, in similar weather and wind conditions and using the same spikes. A photocell timing system (Witty tireless timing system, Microgate, Bolzano, Italy) was used for recording the sprinting times. Both photocells were placed at the same height in all the tests performed by the different participants (60 cm) as the placement of the photocells at different heights can cause variations in the times recorded (Cronin and Templeton, 2008). To avoid interference of one test in another test, Pre and post-tests were performed in the following distribution: Day 1: CMJ–PSQ and day 2: SJ, 30S and 30F.

4.2.3 Handling Data

Data were presented as mean ± standard deviation. Due to the small sample size, we considered the value of the effect size as measured by Cohen's d, and the percentage change (PC) between pre and post-tests in both groups. This is because the thorough application of inferential statistics, e.g., t-test or ANOVA, can be misleading in this type of sample where differences between groups at the $p < 0.05$ level may not be properly identified (Rhea, 2004). However, to ensure no differences at the baseline among groups, we conducted a Mann-Whitney U-test for independent variables comparing AL and NAL group performances in the pre-test battery. Descriptive data were showed about the estimated vs. performed velocity progression in ST for each subject in the Figure 4.1. Analyses were done with Jamovi 2.2.5 for Windows.

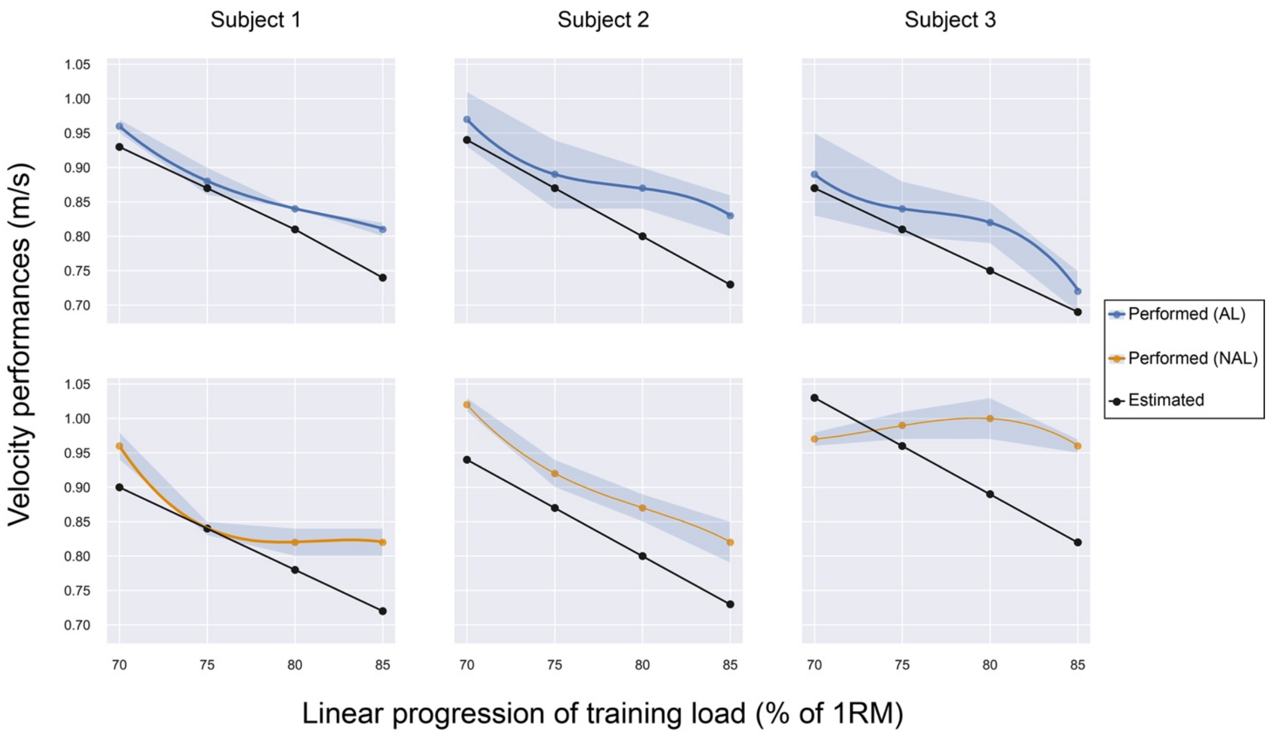

Figure 4.1. Regression plot showing the estimated vs. performed velocity progression in ST for each subject. The colored points representing the two groups (blue for the AL group, orange for the NAL group) refer to the average peak of velocities obtained during the ST at that specific percentage of 1RM.

4.3 Results

The Mann-Whitney U-test indicated that there was no significant difference between the pre-test performances of the AL and NAL groups, $U = 5$, $p = 1$ for all the pre-test battery. This showed that the two groups were homogeneous in terms of squatting, jumping, and running performances at the baseline. Moreover, the post-test analysis showed that the PC in squatting (PSQ) and jumping (CMJ and SJ) performances were all positive, signaling that the participants enhanced their expressions of vertical force abilities after the concurrent ST and usual track and field training. Furthermore, these changes were greater in the AL group compared to the NAL group. However, regarding the running performances (30S and 30F tests), the NAL group obtained a small, negative percentage change (0.65%) in the 30S test, whereas the AL group performed minimally better than pre-test (−0.16%). Besides, both groups slightly improved their performance in the 30F post-test (−1.98% and −1.10%, respectively). The Cohen's d ranged from very small to medium effect sizes. In particular, the effect sizes were the highest in squatting and jumping performances for both groups, reporting medium effects for the PSQ (0.60 in the AL group) and CMJ (0.62 in the NAL group). Additionally, the AL group presented higher effect size in the PSQ (0.60 vs. 0.35 in the NAL group), whereas the NAL group had the higher effects in CMJ (0.63 vs. 0.41 in the AL group) and SJ (0.40 vs. 0.30 in the AL group). On the contrary, the smallest effects concerned the running performances, ranging from 0.04 for the 30S in the AL group, to 0.28 for the same test in the NAL group (Table 4.2).

Table 4.2. Results from the pre and post-test battery. For both groups, the percentage changes and effect sizes were the highest when considering squatting and vertical jumping performance, i.e., in the PSQ, CMJ, and SJ tests.

	AL				NAL			
	Pre-test	Post-test	PC	d	Pre-test	Post-test	PC	d
PSQ (kg)	115.31 ± 27.80	131.97 ± 36.64	14.45	0.60	108.83 ± 27.57	118.57 ± 14.92	8.96	0.35
CMJ (cm)	38.67 ± 9.21	42.47 ± 9.91	9.83	0.41	43.40 ± 5.16	46.63 ± 9.54	7.45	0.63
SJ (kg)	30.33 ± 17.47	37.00 ± 23.07	21.98	0.30	32.83 ± 15.94	39.33 ± 14.36	19.80	0.40
30S (s)	4.14 ± 0.16	4.13 ± 0.21	-0.16	0.04	4.11 ± 0.10	4.14 ± 0.18	0.65	0.28
30F (s)	3.37 ± 0.30	3.30 ± 0.29	-1.98	0.22	3.34 ± 0.15	3.30 ± 0.16	-1.10	0.24

Legend: AL = adjusting loads group; NAL = not adjusting loads group; PC = percentage change; d = Cohen's d effect size; PSQ = Parallel squat (kg); CMJ = counter movement jump (cm); SJ = squat jump (kg); 30S = thirty meters standing start (s); 30F = thirty meters flying start (s).

Interestingly, the outcomes from the ST revealed a particular trend regarding the AL group (Table 4.3).

Table 4.3. Progressions of the performed velocity-based ST compared to the estimated one. Performed velocity is reported as the mean of the velocity peaks performed in each session which employed a specific percentage of 1RM.

Group/subject	% of RM	70%	75%	80%	85%

AL, S1	P	0.96 ± 0.01	0.88 ± 0.02	0.84 ± 0.00	0.81 ± 0.01
	E	0.93	0.87	0.81	0.74
AL, S2	P	0.97 ± 0.04	0.89 ± 0.05	0.87 ± 0.03	0.83 ± 0.03
	E	0.94	0.87	0.80	0.73
AL, S3	P	0.89 ± 0.06	0.84 ± 0.04	0.82 ± 0.03	0.72 ± 0.03
	E	0.87	0.81	0.75	0.69
NAL, S1	P	0.96 ± 0.02	0.84 ± 0.01	0.82 ± 0.02	0.81 ± 0.02
	E	0.90	0.84	0.78	0.72
NAL, S2	P	1.02 ± 0.01	0.92 ± 0.02	0.87 ± 0.02	0.82 ± 0.03
	E	0.94	0.87	0.80	0.73
NAL, S3	P	0.97 ± 0.01	0.99 ± 0.02	1.00 ± 0.03	0.96 ± 0.01
	E	1.03	0.96	0.89	0.82

Legend: AL = adjusting loads group; NAL = not adjusting loads group; S = subject; P = performed velocity (m/s); E = estimated velocity (m/s).

Specifically, the difference between the performed and estimated velocities in this group was positive across the entire ST. This meant that the athletes from the AL group systematically performed at higher velocities than the ones we estimated via F-V profiling. However, two distinct tendencies could be identified within the ST load progression. In particular, at 70%—75% of the predicted 1RM, the AL group performed at velocities close to the estimated values, with the difference between performed and estimated velocity ranging from to 0.01–0.03 m/s. Progressing through higher loads, i.e., at 80%—85% of the 1RM, the AL group tended to exceed the predicted velocities, with the difference between performed and estimated velocity rising up from 0.03 to 0.10 m/s (Figure 4.1). The NAL group, on the other hand, showed a more heterogeneous behavior. Namely, within the 70%–75% range of 1RM, the velocity performances could happen to be exactly the same, much higher, or even less than estimated, which was never the case regarding the AL group. Moreover, the differences between performed and estimated velocities were the highest in the NAL group, particularly at 80% and 85% of 1RM, accentuating the trend already shown within the AL group.

4.4 Discussion

The aim of this study was twofold. One objective was to compare the effects of two different squat VBT strategies (AL vs. NAL) for enhancing maximal squatting, jumping, and sprinting performances in track and field athletes. Another intent was to explore whether one VBT strategy was more precise than the other in identifying training intensity mismatching between estimated and performed velocities.

We found that the AL strategy appears to be the most optimal tool within VBT to effectively control the relative intensity across a linear progression of training loads. This seems particularly efficient while training at medium intensities, i.e., 70% and 75% 1RM, whereas this effect is less accurate at higher intensities, i.e., 80% and 85% 1RM. We also found the AL strategy capable of better improving maximal squatting and vertical jumping performances, whereas very little performance changes were found in sprinting performances after the ST intervention.

Effects in physical performance produced by the AL vs. NAL approaches have been previously studied. For instance, Jiménez-Reyes et al., 2021, found that the NAL group obtained significantly greater results than the AL group in back squat 1RM, CMJ and sprint performances after the ST. The authors speculated that this phenomenon could be due to the use of lower loads than the scheduled ones across the ST. They concluded that a stimulus inducing low degrees of fatigue may be enough to elicit strength adaptations in a non-experienced population. Nevertheless, our results contrast with these findings, as we identified greater percentage changes in favor of the AL group in PSQ, CMJ, and SJ after the ST intervention. Nevertheless, NAL obtained greater ES than AL in all tests except from PSQ. This might be because NAL was training at higher velocities than AL (as the relative intensity was lower), working on fast movements, which are found in jumping and sprint actions. In fact, Rodríguez-Rosell et al., 2017, analyzed the effects of light-load training and combined training including heavy loads and they found higher efficacy of transfer of strength gains to sprint ability in light-loads group.

It is also worth mentioning that the two sprinting tests we employed (30S and 30F) revealed minimal percentage changes and ES in both groups. Here, the nature of the population recruited, i.e., national track and field sprinters, could explain the lower effect in these tests. Given that short-distance repeats are a paramount activity for sprinters, our participants were most likely accustomed to sprinting from years of previous training. On the contrary, participants from Jiménez-Reyes et al., 2021, enhanced their performance in short distance sprinting. However, they were physically active men with less experience in sprinting executions, having more room for improving their athletic features than experienced sprinters.

Nonetheless, improvements in sprint performance are not assessed exclusively via outcome measurements, as the one we employed in this study (sprint time). For example, enhancement in sprinting can be analyzed through biomechanical and kinematic factors, e.g., long ground contact times during the acceleration phase (Weyand et al., 2000), or great concentric force production of knee and hip flexors (Dorn, Schache and Pandy, 2012). These factors are also achievable focusing on training and improving maximum strength levels (CORMIE, MCGUIGAN and NEWTON, 2010). Hence, although our participants did not improve their sprint times after the ST, it is still possible that there were improvements concerning other internal factors, which were not evaluated in this study. Remarkably, the AL and NAL groups showed different interactions between estimated and performed velocities. With respect to the AL group, there was a homogeneous trend throughout the ST program. Namely, the gap between the estimated and performed velocities was minimal at lower intensities (from 0.01 to 0.03 m/s at 70%—75% 1RM) Supporting this outcome. Jiménez-Reyes et al., 2021, also found minimal differences between estimated and performed velocity in the AL group. However, the gap in our experiment started to increase during the second half of the ST, where the intensity went progressively up (from 0.03 to 0.10 m/s at 80%—85% 1RM). Seeing that in the AL group the training load was adjusted in each session during the warmup sets, an inefficient warmup protocol could lead the athletes to lift lighter loads than they had to, thus setting a lower 1RM for that particular training session. Therefore, it may be the case that the protocol proposed could have not been enough, in terms of neural activation, to prepare the athletes to perform at high intensities such as 80%–85% 1RM. Perhaps, different timing and loading techniques for optimal neural activations could be used to this scope, e.g., PAP and/or PAPE, ramping techniques, etc.

On the other hand, regarding the NAL group, the estimated and performed velocities followed an inconsistent behavior for every load percentage. That is, each participant presented a singular behavior in terms of intensity progression, with peculiar cases of either matching exactly or performing below the estimated intensity. Despite this, the NAL group tended to perform at higher velocities than the estimated ones, with greater gaps compared to the AL group. Moreover, the gaps even widened as the sessions progressed. For instance, subject 3 followed the most mismatching progression and was training at the same relative intensity during the whole ST. This could be because his training adaptations appeared earlier than the load increment and therefore intensity progression. Training adaptations characteristics depend on a great variety of factors as molecular processes genetically predisposed, nutrition or acclimatization (Hughes, Ellefsen and Baar, 2018). Therefore, training adaptations should be considered individually. In line with our study, Jiménez-Reyes et al., 2021, found significant differences between estimated and performed velocities from session 5 (65% 1RM) onwards in the NAL group.

The main limitation of this study is the small sample size, which may limit the generalizability of the findings. It is important to conduct further research with larger and more diverse samples to confirm the trends observed in this article. Additionally, the low statistical power resulting from only including six participants may lead to potential misinterpretation of critical results. Regardless, there is little scientific literature about this topic, thus a case series study can still be considered an initial piece of valuable information for coaches and scholars who seek to make their designed training loads adhere to the actual strength performances. Furthermore, case studies can serve as a useful communication channel with coaches and may develop hypotheses and effect sizes useful in designing further studies (Halperin, 2018).

4.5 Conclusions

Adjusting ST intensity during VBT produced performance improvements in strength and sprint skills and additionally, holds potential to drive the in-field research towards more efficient training periodization and management throughout the track and field athletes' competitive season. The trend of matching or mismatch between absolute load and relative intensity is observable and a more adequate control is obtained by using the daily load adjustment through velocity. This study provides promising information and preliminary recommendations for coaches who want to adjust the intensity of training to the athlete's daily condition considering factors as internal fatigue.

5. Relationship between Maximum Force – Velocity Exertion and Swimming Performances among Four Strokes over Medium and Short Distances: The Stronger on Dry Land, the Faster in Water?

Abstract. Evaluating force–velocity characteristics on dry-land is of the utmost importance in swimming, because higher levels of these bio-motor abilities positively affect in-water performance. However, the wide range of possible technical specializations presents an opportunity for a more categorized approach that has yet to be seized. Therefore, the aim of this study was to identify feasible differences in maximum force–velocity exertion based on swimmers' stroke and distance specialization. To this scope, 96 young male swimmers competing at the regional level were divided into 12 groups, one for each stroke (butterfly, backstroke, breaststroke, and front crawl) and distance (50 m, 100 m, and 200 m). They performed two single pull-up tests, 5-min before and after competing in a federal swimming race. We assessed force (N) and velocity (m/s) exertion via linear encoder. There were no significant differences between pre-post maximum force–velocity exertions, despite the decreasing trend. Force-parameters highly correlated with each other and with the swimming performance time. Moreover, both force ($t = -3.60$, $p < 0.001$) and velocity ($t = -3.90$, $p < 0.001$) were significant predictors of swimming race time. Sprinters (both 50 m and 100 m) of all strokes could exert significantly higher force–velocity compared to 200 m swimmers (e.g., 0.96 ± 0.06 m/s performed by sprinters vs. 0.66 ± 0.03 m/s performed by 200 m swimmers). Moreover, breaststroke sprinters presented significantly lower force–velocity compared to sprinters specialized in the other strokes (e.g., 1047.83 ± 61.33 N performed by breaststroke sprinters vs. 1263.62 ± 161.23 N performed by butterfly sprinters). This study could provide the foundation for future research regarding the role of stroke and distance specializations in modeling swimmers' force–velocity abilities, thus influencing paramount elements for specific training and improvement towards competitions.

5.1 Introduction

Swimming can be defined as a closed-skills sport, i.e., a sporting activity in which the environment is relatively highly consistent, predictable, and self-paced for performers (Wang et al., 2013). Within this setting, the sole sport-specific practice cannot grant the swimmers a great enough stimulus to maximize their gestures (Amaro et al., 2017; Crowley, Harrison and Lyons, 2018; Sadowski, Mastalerz and Gromisz, 2020). Therefore, along with the acquisition of certain technical skills, the appropriate development of bio-motor abilities such as strength, power, and endurance are considered the key to success in competitive swimming (Mujika et al., 2018; Muniz-Pardos et al., 2019).

In particular, strength can be described as the ability of the neuromuscular system to produce force against external resistance (Komi, 1994; Bompa and Buzzichelli, 2019) and it has been repeatedly speculated to be the crucial bio-motor ability for the development of optimal swimming performance (Berryman, Mujika and Bosquet, 2019; Lum and Barbosa, 2019; Duchateau et al., 2021). In this regard, some investigators advocate the paramount role of strength with a deduction: if higher levels of strength mean a higher capacity to produce force against water resistance, then consequently this will improve the swimmers' velocity and ultimately their swimming performance (IKUTA et al., 2010; Costa et al., 2015). Seeking to expand upon this compelling aspect, several scholars have in fact confirmed that there is a close relationship between the capacity of producing high forces and superior swimming performances. To this scope, a reliable tool used to assess swimming-specific strength (both on dry land as well as in the water) is the evaluation of force–velocity exertion, which basically dictates the relationship between the load lifted and the speed it can be moved (Gonjo et al., 2021; Pleša, Kozinc and Šarabon, 2022). Specifically, it has been shown that high levels of maximum strength in various exercises (e.g., bench press, pull-up, back squat, horizontal rows, etc.) correlate with many technical components of a swimming race, such as trunk stability during the stroke, gliding phase, diving phase, turning phase, stroke length, stroke frequency, and stroke index (Garrido et al., 2010; Pérez-Olea et al., 2018; Carvalho et al., 2019; Born et al., 2020; Hermosilla et al., 2021, 2022), ultimately translating into optimized swimming velocity (Lopes et al., 2021). Nonetheless, vertical pulling gestures are the most used and effective motions for evaluating force–velocity production in swimming performances (Crowley et al., 2018; Born et al., 2020). In particular, it has been shown that the maximum velocity and force generated during the pull-up exercise highly correlates with swimming velocity (Pérez-Olea et al., 2018). These findings well demonstrate the effectiveness that well-developed bio-motor abilities, assessed through force–velocity parameters on dry land (Carvalho et al., 2019), hold on swimming performance.

However, despite this promising body of research, the extensive heterogeneity lying within competitive swimming raises several issues that are yet to be ascertained. For instance, one critical element concerns the broad technical outlook, i.e., the four “cardinal” swimming strokes (butterfly, backstroke, breaststroke, and front crawl). Although most of the literature is focused on the front-crawl stroke (Martens, Figueiredo and Daly, 2015; Dundar, Kocahan and Arslan, 2019), it is worth noting that the butterfly, backstroke, and breaststroke “styles” are highly specific as well as biomechanically and kinematically different from each other (Gonjo et al., 2020). Based on the unique characteristics of each stroke, it could be that their differences are also reflected in the force–velocity exertion of specialized swimmers. If that is the case, it would then be possible to outline the ideal bio-motor features of swimmers who concentrate their endeavors on a particular stroke.

Another issue pertains to the numerous distances that are swum in swimming races, which dictate the athletes’ specialization from a bio-energetical standpoint. On this subject, suitable research has highlighted the diverse aerobic, anaerobic, and technical demands that reside among sprint and medium- and long-distance swimming races (Aspenes and Karlsen, 2012; Dundar et al., 2019). Nevertheless, it should be considered that medium-distance sporting activities (as a 200 m swimming race would be defined) also seem to benefit from the high capacities of producing muscular force (Kavanaugh, 2008; González Ravé, 2021; González-Ravé et al., 2022). Seeing these ambiguous findings, there is a need to clarify whether measures of force–velocity significantly change depending on different swimming distances, eventually drawing out the implications in terms of building superior in-water performances based on distance specialization.

As we argued in the paragraph above, when it comes to dissecting how force–velocity levels pertain to various swimming specialties during training, the current literature presents more questions than answers. Still, these uncertain aspects provide appealing opportunities for further inquiries. With these considerations in mind, in the present study, we sought to evaluate the relationship between maximum force–velocity exertion and swimming performances in male regional-level swimmers, examining and comparing both medium (200 m) as well as short (50 and 100 m) distances; all the four strokes swum in competitions; and the amount of neuromuscular fatigue generated by the competition, collecting force–velocity data shortly before and after the swimming race. The single pull-up test, performed for one repetition exerting maximum force, was used to evaluate the swimmers’ force–velocity production, whereas the official time of the respective swimming race (swum in a short course of 25 m) was considered as an indicator for swimming performance.

Ultimately, the purpose of this article is to clearly define to what extent maximum force–velocity capacities and swimming performances relate to each other when considering the intrinsically different bio-motor and technical facets of athletes specialized in a certain stroke and distance, also exploring whether and how this relationship is altered due to neuromuscular fatigue after performance. Overall, this additional knowledge would make it possible to draw evidence-based indications in order to further elevate swimming performance, favoring both academics for more profound investigations as well as coaches and athletes striving to attain ever-better competitive forms.

5.2 Materials and Methods

5.2.1 Participants

A homogeneous group of 96 male swimmers competing at the regional level took part in the study (16 ± 1.3 years of age; height of 175 ± 2.7 cm; weight of 69 ± 2.2 kg; 6.5 ± 1.1 years of experience; 466 ± 21 Fédération Internationale De Natation points of best competitive performance). Specifically, we divided the subjects per stroke (i.e., butterfly, backstroke, breaststroke, and front-crawl) and distance (i.e., 50, 100, and 200 m), therefore assigning eight subjects per group. All of the participants reported no physical injuries prior to or during the duration of the study. Moreover, the subjects were already familiar with the pull-up motion from their previous training experience. The participants were all tested individually. All of the subjects provided assent and the parents/guardians provided informed consent after a detailed description of the study procedures. The study was approved by the local Ethics Committee of the university (FGM02102019) and was conducted in accordance with the Declaration of Helsinki.

5.2.2 Set up, Tasks, Procedure

The subjects performed the single pull-up tests and concurrent swimming race at the end of their preparatory cycle of training (i.e., 8 weeks after the start of the season). The experiments were performed inside a regular, short-course (25 m) competitive swimming facility, during competition days. In particular, the single pull-up tests were performed in a large, quiet room inside the facility and near the pool. Furthermore, the pull-ups were performed using a standard steel bar of 3.81 cm in diameter (1.5 inches), standing 2.50 m from the ground.

Prior to the start of the experiment, the participants were advised to perform two single pull-up tests, with the first test taking place 5 min before the swimming competition and repeating the same test 5 min after the aforementioned competition. Specifically, the subjects were instructed to perform one repetition of the pull-up motion, exerting the highest force possible (i.e., pulling as strong and fast as they can). Moreover, the subjects had to follow precise criteria regarding the pull-up execution; first, they had to reach for the bar with a prone grip, without their feet touching the ground and by maintaining their arms and elbows straight. This was considered the starting position of the pull-up test. From this hanging position, after a brief verbal cue ("Ready, go"), the subject would then perform the pull-up, which had to be executed without any movement of the legs and passing with the chin over the bar. To ensure the procedure for measuring pull-ups 5 min before and 5 min after the swimming races, we employed a stopwatch. According to Kraemer and Fragala, 2006, 5 min is considered a long rest period, capable of dissipating the amount of fatigue experienced during anaerobic physical exertions. According to this information, we used the 5 min rest period to ensure enough recovery pre-competition and to also establish the same rest period after the competition.

In order to prepare for the competitions, the subjects first executed 20 min of warm-up. Specifically, the warm-up was 20 min long and consisted in the first part (about 5 min) being performed on dry land using body weight (e.g., squats) and elastic bands exercises (e.g., shoulders horizontal internal and external rotation), whereas the second part (about 15 min) was performed in-water and included sport-specific drills and exercises (i.e., turns, underwater glides, swimming at various paces and stroke rhythms), performed at light intensity. After 20 min of warm-up (i.e., 5 min before the respective swimming race), the subject came into the testing room. In order to register the force–velocity data, the linear encoder was attached to the subjects' hips through a harness. The linear encoder was instead attached to the ground, within the same vertical plane as the subjects. In this way, it was possible to collect accurate data with minimal invasiveness. After that, the subjects performed the single pull-up test according to the criteria explained above. Five minutes after the single pull-up test, the subjects took part in the federal swimming race assigned. Each swimmer took part in only one race. Another five minutes after the swimming race, the subjects returned and performed a second single pull-up test following the same experimental setup. Each swimmer that was recruited for this study was tested individually for both the dry land and in-water performance assessments. However, given the competitive nature of this experimental setting, the subjects competed in the swimming races with other athletes who did not take part in this study.

5.2.3 Handling Data

We collected data regarding the in-water performances and the force–velocity parameters. As for the in-water performance, swimming race times were collected during federal swimming races by professional personnel employed in the local swimming federation. As for the force–velocity parameters in the ascending phase of the single pull-up test, velocity (m/s) and force (N) were collected using the Vitruve linear encoder (Speed4Lifts, Madrid, Spain). Specifically, this linear encoder comes in the portable form of an 8 cm3 box, equipped with an extensible wire that is attachable via a Velcro strap. Moreover, the Vitruve linear encoder is embedded with a smartphone app that allows for insertion of the subject's height and weight, consequently calculating specific performances in a selected exercise (in this case, the pull-up). In particular, we used the velocity-based data registered by the encoder (i.e., power and velocity) to provide the force values.

The data were analyzed using IBM SPSS Statistics 26 software. Parametric analyses were conducted as the Shapiro–Wilk test revealed a normal distribution of data ($p > 0.05$). First, we checked for test–retest reliability taking advantage of the two force–velocity assessments we made within this experimental setup. The resulting correlation coefficient was 0.81, therefore indicating an instance of good test–retest reliability. Then, detriments in the pull-up performance due to neuromuscular fatigue were sought using the ANOVA repeated measures test for both the velocity and the force generated before and after the swimming race. Furthermore, the Pearson correlation coefficient was used to define the levels of dependence among the force and the velocity in the single pull-up test and the time of the swimming races. Moreover, we used a multiple linear regression model to quantify the relationship between the velocity and force in the single pull-up test with the time of the swimming races. Finally, we implemented one-way ANOVA followed by the Bonferroni post-hoc test for multiple comparisons in order to detect differences in velocity and/or force exerted in the single pull-up test among strokes and distance specialties.

5.3 Results

The fatigue generated by the swimming performances affected both the velocity as well as the force in the single pull-up test (Table 5.1).

Table 5.1. Descriptive table of results.

		Velocity (m/s)			Force (N)		
Group	**T (s)**	**Pull-Up Pre**	**Pull-Up Post**	**Fatigue (%)**	**Pull-Up Pre**	**Pull-Up Post**	**Fatigue (%)**
Bu 50	27.35 ± 1.14	0.97 ± 0.07	0.95 ± 0.07	−2.33	1263.62 ± 161.23	1223.97 ± 155.62	−3.09
Ba 50	29.88 ± 0.96	0.95 ± 0.06	0.93 ± 0.06	−2.5	1230.66 ± 116.82	1194.58 ± 111.24	−2.88

		Velocity (m/s)			Force (N)		
Group	**T (s)**	**Pull-Up Pre**	**Pull-Up Post**	**Fatigue (%)**	**Pull-Up Pre**	**Pull-Up Post**	**Fatigue (%)**
Br 50	32.19 ± 0.89	0.79 ± 0.03	0.76 ± 0.03	−2.86	1047.83 ± 61.33	1016.11 ± 66.81	−2.95
FC 50	24.86 ± 0.87	0.96 ± 0.06	0.94 ± 0.05	−2.15	1247.48 ± 137.14	1211.46 ± 140.39	−2.85
Bu 100	60.49 ± 1.16	0.88 ± 0.02	0.86 ± 0.02	−2.27	1175.36 ± 53.48	1146.21 ± 55.09	−2.45
Ba 100	63.82 ± 2.32	0.88 ± 0.05	0.86 ± 0.05	−1.71	1151.48 ± 31.28	1111.98 ± 29.45	−3.39
Br 100	71.72 ± 2.19	0.77 ± 0.03	0.75 ± 0.03	−2.25	1024.42 ± 29.51	999.12 ± 26.57	−2.43
FC 100	53.63 ± 1.18	0.93 ± 0.04	0.92 ± 0.03	−1.72	1188.69 ± 55.30	1156.16 ± 58.93	−2.68
Bu 200	151.16 ± 13.33	0.66 ± 0.03	0.65 ± 0.04	−2.28	963.63 ± 28.62	925.44 ± 31.56	−3.9
Ba 200	144.79 ± 8.13	0.67 ± 0.03	0.65 ± 0.03	−2.61	960.82 ± 29.90	930.14 ± 28.98	−3.11
Br 200	158.45 ± 4.49	0.67 ± 0.03	0.66 ± 0.03	−2.24	957.55 ± 34.13	932.50 ± 36.60	−2.56
FC 200	120.63 ± 4.71	0.69 ± 0.04	0.67 ± 0.04	−2.52	966.85 ± 33.89	940.01 ± 27.95	−2.69

Abbreviations: T = time of the swimming race; Bu = butterfly; Ba = backstroke; Br = breaststroke; FC = front crawl; fatigue (%) = percentage change between pull-up pre and pull-up post the swimming race. The numbers “50”, “100”, and “200” next to each group indicate the distances in which the swimmers specialized.

Specifically, the pre-post percentage difference in velocity ranged from −1.71% in the 100 m backstroke group to −2.86% in the 50 m breaststroke group, whereas the percentage difference in force ranged from −2.43% in the 100 m breaststroke group to −3.39% in the 100 m backstroke group. However, the ANOVA repeated measures test reported no statistically significant differences in either velocity ($F(96, 1) = 1.89$, $p = 0.17$) and force ($F(96, 1) = 2.33$, $p = 0.35$) among the groups. While including a control group to test for fatigue after the swimming race would improve the experimental design, we have no reason to believe that the general loss in force–velocity post-competition was not due to the swimming race, which was the only physical stimulus occurring between the pre- and post-evaluations. Moreover, we employed more than enough recovery time regarding the single pull-up tests before and after the swimming race (i.e., 5 min) (Kraemer and Fragala, 2006). Consequently, it was reasonable to expect similar values of force–velocity performances from the subjects, which was only partially the case. However, we again specify that this trend did not achieve statistical significance, and thus can only be seen as a speculative interpretation of the phenomenon.

Considering the whole sample of subjects (n = 96), the application of the Pearson r coefficient revealed a strong correlation between velocity and force (0.94 and 0.93 for the pull-up pre and post competition, respectively), suggesting that these two parameters may describe the same trend in this context. Likewise, the correlation between the swimming race time and force in the pull-up test was −0.74 both pre and post competition, whereas the correlation between the swimming race time and velocity during the pull-up test was −0.86 both pre and post competition, indicating that stronger/faster performances in the single pull-up test correlate with lower (thus better) swimming race times. Moreover, this strict correlation between force and velocity indicates that there is an almost linear relationship between them (i.e., more force generated means reaching a higher velocity and vice versa) (Figure 5.1).

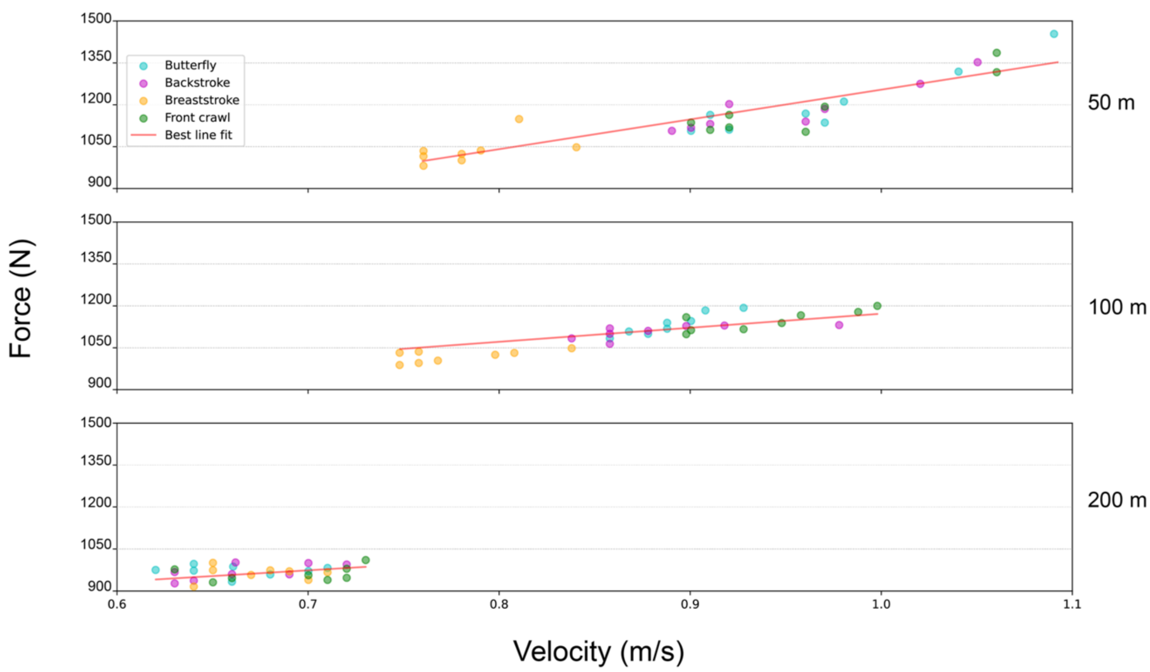

Figure 5.1. Scatter plot showing the maximum force–velocity exertion of the swimmers, grouped by stroke, and differentiated by swimming race distance. As shown by the best line fit, the high correlation between the force and velocity values in the single pull-up test reflects an almost linear trend. This is particularly evident within the 50 m and 100 m groups of swimmers.

Multiple linear regression was calculated to predict swimming race times based on the velocity and force generated in the single pull-up test, before the competition. In order to include all of the results in the same explanatory model, we standardized the swimming race times for each distance and stroke, calculating the respective z-scores. In a similar way, given the differences occurring in both force and velocity requirements in the single pull-up test among the experimental groups, the independent variables (i.e., velocity and force) were also standardized by z-scores. It is necessary to standardize the values since the explanatory variables in regression models have different scales and different levels of size. Considering the multiple linear regression analysis, a significant regression equation was found ($F(2, 93) = 78.17$, $p < 0.001$), with an R2 of 0.81 and an R2 adjusted of 0.80 (Table 5.2).

Table 5.2. Multiple linear regression analysis to predict swimming performances based on z-scored velocity and force generated in the single pull-up test. The analysis considers both the distance and stroke groups.

ANOVA					
Model	DF	Sum of Square	Mean Square	F Statistic	p-Value
Regression	2	33.77	16.88	78.17	<0.001
Residual	93	50.09	0.54		
Total	95	83.86	0.88		
Coefficients (R-square = 0.81; adjusted R-squared = 0.80)					
Model	Estimate	Standard Error	t-Value	p-Value	
(Constant)	3.03×10^{-14}	0.075	1.08	0.28	
Velocity (z-score)	−0.046	0.126	−3.90	<0.001	
Force (z-score)	−0.037	0.121	−3.60	<0.001	

In particular, the swimmers' predicted race time was equal to 3.03 × 10−14—0.046 (velocity)—0.037 (force). It should be noted that positive z-score values indicate values above the group mean; therefore, an increased z-score represents an increase in either the velocity or the force. Specifically, the model showed that a unitary increase in the velocity z-scores resulted in a decrease in the target variable (z-point, i.e., the swimming race time) of 0.046 s, whereas a unitary increase in the force z-scores predicted a slightly smaller decrement of 0.037 s. Bearing in mind that positive z-point values correspond to swimming race times above the mean and vice versa, the above behavior indicates that the higher the velocity or force generated by the athletes, the shorter their swimming race time. In addition,

both the velocity (t = −3.90, $p < 0.001$) and force in the pull-up tests (t = −3.60, $p < 0.001$) were significant predictors of swimming race time.
Finally, the one-way ANOVA was performed to compare the differences in velocity and force based on stroke and distance (Table 5.3).

Table 5.3. ANOVA tables for velocity (m/s) and force (N) in the single pull-up test before the swimming competition.

Velocity (m/s)					
Source	**DF**	**Sum of Square**	**Mean Square**	**F Statistic**	**p-Value**
Groups (between groups)	11	1.36	0.12	66.80	<0.001
Error (within groups)	84	0.16	0.0019		
Total	95	1.52	0.016		
Force (N)					
Source	**DF**	**Sum of Square**	**Mean Square**	**F Statistic**	**p-Value**
Groups (between groups)	11	1,329,427.64	120,857.06	19.60	<0.001
Error (within groups)	84	517,981.89	6166.45		
Total	95	1,847,409.53	19,446.42		

Regarding the validation of the test, although the a priori power was low (0.28), the null hypothesis was still rejected. Moreover, the one-way ANOVA revealed that there was a statistically significant difference in both velocity ($F(11, 84) = [66.80]$, $p > 0.001$) as well as force among the groups of swimmers ($F(11, 84) = [19.60]$, $p > 0.001$).
Specifically, Table 5.4 reports the Bonferroni post-hoc test for multiple comparisons.

Table 5.4. Bonferroni post-hoc comparisons test for velocity (m/s) and force (N) across the experimental groups. The mean differences are shown. The asterisk * shows that the mean difference is significant at the 0.05 level. Interestingly, most of the significant post-hoc differences in velocity corresponded to the same significant post-hoc differences in force among the experimental groups, further strengthening the suggestion that the velocity and force generated executing a vertical pulling motion are (almost) linearly intertwined.

Velocity (m/s)								
	Distance				**Distance**			
Stroke	50	100	200		50	100	200	
Bu	0.02	0.004	0.003	Ba	0.17*	0.11 *	0.07	Br
Bu	0.20*	0.11 *	0.08	Br	0.18 *	0.16 *	0.02	FC

Bu	0.001	0.05	0.03	FC	0.01	0.06	0.03	Ba

Force (N)								
	Distance				**Distance**			
Stroke	50	100	200		50	100	200	
Bu	32.96	23.88	2.81	Ba	182.83*	127.07*	3.27	Br
Bu	215.79*	150.95*	6.08	Br	199.65*	164.28*	9.3	FC
Bu	16.14	13.33	3.22	FC	16.82	37.20	6.03	Ba

Abbreviations: Bu = butterfly; Ba = backstroke; Br = breaststroke; FC = front crawl. The asterisk * shows that the mean difference is significant at the 0.05 level.

A fascinating aspect emerging from the post-hoc analysis is that almost all the significant differences between the groups in velocity corresponded to the same significant differences between groups in force, with the only exceptions being between the 200 m backstroke and the 50 m breaststroke (i.e., the mean difference in velocity was 0.12 ± 0.09 and statistically significant, whereas the mean difference in force was 87.01 ± 61.48 and not statistically significant) and between the 50 m breaststroke and 100 m front crawl (i.e., the mean difference in velocity was 0.15 ± 0.10 and not statistically significant, whereas the mean difference in force was 140.86 ± 99.54 and statistically significant). This further confirms the assumption that within this experimental setting, there is an almost linear relationship between maximum force and velocity productions.

When grouping the swimmers by stroke specialization, the 50–100 m sprinters were significantly faster and stronger in the single pull-up test than the 200 m middle-distance swimmers (Figure 5.2).

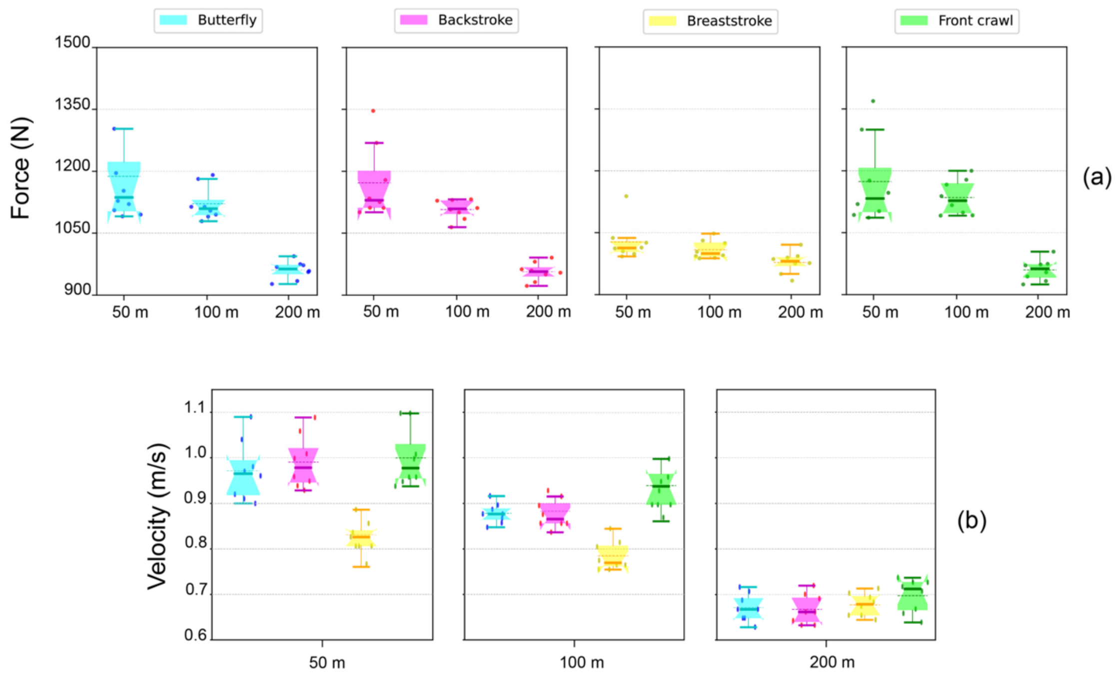

Figure 5.2. Scatter box plot showing the maximum force (N; panel (a)) and velocity (m/s; panel (b)) exerted in the single pull-up test, before the swimming competition. (a) Within all four strokes, a trend emerged where the sprinters (both 50 m and 100 m) could exert significantly higher forces compared to the medium-distance swimmers. Although it remained statistically significant, this trend was less evident regarding the breaststroke swimmers. (b) The 50 m and 100 m breaststroke swimmers presented significantly lower levels of velocity in the single pull-up test compared to the swimmers of other strokes competing in the same distance. However, this was not the case with the group of 200 m swimmers, where there were no significant differences among the groups.

Despite still being statistically significant, this tendency was quantitatively less prominent for the breaststroke performers. Instead, when categorizing the swimmers by the same race distance, we observed significant differences in maximum force–velocity exertion among breaststroke sprinters (i.e., 50 m and 100 m) and the other three strokes (i.e., butterfly, backstroke, and front crawl, both in 50 m as well as 100 m). Specifically, the 50 m and 100 m breaststroke performers presented significantly worse force–velocity parameters in the single pull-up test than their butterfly, backstroke, and front crawl peers (Figure 5.2). Regarding the 100 m swimmers, although there were no significant differences in force–velocity values compared to their 50 m counterparts, the force–velocity peaks were always reached by the 50 m sprinters. Furthermore, this behavior was not present in the middle-distance (i.e., 200 m) swimmers, which showed no significant differences from one stroke to another, although their maximum force–velocity exertions were all significantly lower compared to the 50 m and 100 m strokes.

5.4 Discussion

In the present study, we sought to explore the relationship between maximum force–velocity exertion and competitive performances in regional-level swimmers, specialized both for stroke (i.e., butterfly, backstroke, breaststroke, or front crawl) and race distance (i.e., 50, 100, or 200 m). The purpose of this investigation was to leverage a reliable and robust assessment method of the athletes' bio-motor abilities in order to acknowledge trends, patterns, and differences capable of bringing valuable insights for highly specialized performance enhancements in swimming.

In previous review articles, it has been argued that more accomplished swimmers presented significantly lower energy expenditure, especially among swimmers specialized in middle-distance and long-distance races (Barbosa et al., 2006; Pyne and Sharp, 2014; Costa et al., 2015; Gonjo and Olstad, 2020). This was due to energy expenditure being a more limiting factor in swimming races from 400 m to 1500 m than neuromuscular-fatigue-related variables in 50 m, 100 m, and 200 m swimming races. According to the work of Pyne and Sharp, 2014, this implied that there could be a considerable effect of stroke and distance specialization on "swimming economy" and energy system management, which could be investigated by measuring neuromuscular energy expenditure in sprinters and middle-distance swimmers. Nevertheless, although our findings highlighted a trend of a general reduction in both velocity and force generated in the single pull-up test shortly after the swimming competition (Table 5.1), the ANOVA repeated measures revealed no significant differences between the pre- and post-evaluations ($F(96, 1) = 1.89$, $p = 0.17$ concerning velocity and $F(96, 1) = 2.33$, $p = 0.35$ concerning force, respectively). Thus, in contrast with the above-mentioned measurement (i.e., VO_2 max consumption), neuromuscular energy expenditure does not seem to be a specific enough method to assert either specific performance features or differences among stroke/distance specializations in swimming.

We found a strong correlation in the form of the Pearson r coefficient between force (N) and velocity (m/s) parameters in the ascending phase of the single pull-up test (i.e., 0.94 and 0.93 for the pull-ups pre and post competition, respectively). This outcome confirms the results of other recent investigations which have suggested concentrating dry-land training efforts on enhancing the neuromuscular abilities of swimmers, particularly on the integration and coordination of musculature to perform specific tasks under high loads or in an explosive fashion (Gonjo et al., 2020, 2021; Hermosilla et al., 2021). Similarly, the same analysis showed a high degree of correlation between the swimmers' maximum force–velocity exertion and their respective race times (i.e., −0.74 between the force and swimming race time and −0.86 between the velocity and swimming race time). In this regard, we are in line with the research work conducted by Perez-Olea et al., 2018, which showed that the 50 m front crawl swimming time was highly correlated with force–velocity variables of the ascending phase of the single pull-up test. Moreover, our multiple linear regression analysis further substantiates the validity of the pull-up motion mechanics to predict swimming performance in trained swimmers (Table 5.2). Hereof, the beta coefficients (i.e., velocity and force z-scores) were both negative. This means that the higher the value of these beta coefficients, the shorter the time in the swimming race, ultimately resulting in a better competitive outcome. These findings further promote the analysis of pull-up mechanics as a valid, efficient, and reliable means to both calibrate and predict crucial aspects of competitive swimming performances. Concerning this aspect, it is worth noting that we designated the swimming race times as a measure of in-water performance. However, it would be interesting to expand upon this research topic also considering more specific aspects that effectively contribute to the final performance. For instance, analyzing measures of technical proficiency such as stroke length, stroke index, stroke frequency, drag area during stroke, etc., could provide further support in understanding how maximum force–velocity exertion reshapes based on the swimmers' stroke-distance specialization and how scholars and coaches could leverage these distinctions to enhance highly specific elements of swimming performance.

Among all the strokes, the 50 m and 100 m sprinters had significantly higher force–velocity values in the single pull-up test than the 200 m middle-distance swimmers (Table 5.4). Nonetheless, despite maintaining statistical significance, this trend was flattened for the breaststroke performers compared to the other three strokes (Figure 5.2).

In terms of swimming performance optimization, we confirm that the ability to produce higher amounts of force–velocity can indeed be useful in improving swimming race times, especially in sprinters (Carvalho et al., 2019; Born et al., 2020; Lopes et al., 2021). However, our results also indicated that force–velocity values tended to be lower in competitors specialized in middle-distance races (Figure 5.2). In this regard, it is well established that the specific contributions of various energetic systems depend on both the length of the race and the intensity of the pace used (Kraemer and Fragala, 2006). Specifically, middle-distance competitors may prioritize the maximization of aerobic capacities in lieu of force–velocity abilities, which are more related to anaerobic capacity and neuromuscular factors (Pérez-Olea et al., 2018; Hermosilla et al., 2022). Furthermore, this bio-energetic shift necessitates ulterior technical adjustments such as maintaining stroke efficiency (i.e., sustaining parameters of stroke length, stroke frequency, and stroke index) for a longer time compared to 50 m and 100 m swimming races (Barbosa et al., 2006; Pyne and Sharp, 2014). The generally lower force–velocity values in middle-distance swimmers may be also favored by the greater configuration of technical parameters from a tactical–strategical perspective, which is less present in sprinting competitions (Pyne and Sharp, 2014).

Still, there are several reasons to advocate for a leveling up of maximum force–velocity levels even in middle-distance swimmers competing at the regional level. For instance, in the present study, we found a considerable correlation between higher productions of force–velocity and superior swimming performances, including the 200 m performers. Moreover, this is in line with several scholars who observed that underdeveloped levels of force–velocity can result in an early deterioration of technical skills due to the accumulation of neuromuscular fatigue (Bompa and Buzzichelli, 2019). These aspects would also definitely benefit the in-water performance of middle-distance swimmers. Therefore, we strongly encourage trainers to fill the apparent gap in bio-motor skills between sprinters and middle-distance swimmers, providing the latter with more focus and training time to upgrade their force–velocity capacities.

In addition, possible alterations in maximum force–velocity production due to specific training periods should be considered (Mujika et al., 2018). For instance, in this study, we collected force–velocity data at the end of the swimmers' preparatory cycle of training (i.e., after the first 8 weeks of training). However, considering both the differences in training as well as the significant gap in bio-motor abilities that we found between sprinters and 200 m performers, it may be that the force–velocity capacities of middle-distance swimmers are greatly susceptible to the variations in training intensity and volume occurring over the season (e.g., from the preparatory cycle of training to the competitive cycle of training). For these reasons, we recommend future studies to carefully analyze hypothetical fluctuations in swimmers' force–velocity levels over a competitive season and how these fluctuations may affect swimming performances, especially for middle-distance swimmers.

Notably, we found a significant gap in maximum force–velocity production in breaststroke sprinters compared to the other 50 m and 100 m strokes (Figure 5.2). Indeed, we should account for some technical and biomechanical restraints regarding stroke velocity and general efficiency in breaststrokes, especially compared to the butterfly, backstroke, and front-crawl styles of swimming. Here, the basic assumption is that in order to reach, maintain, and increase in-water velocity, swimmers must continuously generate muscular propulsive forces to "fight" and exceed the drag forces of water. However, it is worth mentioning that breaststroke swimming produces the largest intracycle velocity variability among the four strokes (Pyne and Sharp, 2014). This is due to the added drag of recovering both arms under the water and in drawing the knees up to prepare for the next propulsive phase of the stroke cycle. In fact, breaststroke is the sole stroke that does not contemplate the arm-pushing phase. Instead, it is the lower body that is responsible for the active propulsive phase during the stroke. Moreover, it has been shown that the energy expenditure during butterfly and breaststroke swimming is approximately twofold greater than in backstroke or front-crawl swimming (Pyne and Sharp, 2014). Again, this was due to the increase in form drag dictated by the mechanics of these strokes. However, despite both butterfly and breaststroke sharing a symmetrical movement pattern, the breaststroke was shown to be the least efficient stroke in terms of energy expenditure and general in-water velocity. In fact, Pyne and Sharp, 2014, observed that the front crawl presented the lowest energy cost (1.23 kJ/m−1), followed by backstroke (1.47 kJ/m−1), butterfly (1.55 kJ/m−1), and breaststroke (1.87 kJ/m−1). Moreover, the swimming energy cost increased exponentially with an increase in swim velocity during freestyle, backstroke, and butterfly, but this change was linear in breaststroke (Pyne and Sharp, 2014)

In this regard, our findings transpose the in-water biomechanical disadvantages of breaststroke specialists into dry-land bio-motor disparities. The apparent bio-motor limitations on dry-land, the higher complexity of neuromuscular coordination between upper and lower limbs, as well as the inferior mechanical efficiency, put breaststroke in a unique as well as critical position regarding specific performance evaluation and improvement. All of the evidence considered, it may be that breaststroke performers depend more on maximizing their technical ability instead of their force–velocity production in a vertical pulling motion. In addition, given the major involvement of the lower body in generating propulsive forces during breaststroke, it is possible that the different contributions of the legs would be reflected in different force–velocity exertions between breaststroke and the other three strokes. In particular, we would suggest testing this hypothesis using either the back squat or bodyweight vertical jumps (e.g., countermovement jump), which are the most used and effective motions for indirectly improving the "lower-body-focused" elements of swimming races (i.e., diving and turning; Pérez-Olea et al., 2018; Crowley et al., 2018; Born et al., 2020).

This study is not exempt from limitations. Namely, the subjects enrolled had very specific characteristics regarding their competitive level (regional), training experience (6.5 ± 1.1 years of experience), and gender (male). On the one hand, the sample homogeneity allowed us to thoroughly analyze and compare several aspects of maximum force–velocity exertion and swimming performances. On the other hand, we cannot state if the findings from the present study would be confirmed either in athletes competing at the national/international level, holding more years of experience, or considering a population of female swimmers. Moreover, we only recruited swimmers specialized in a single stroke;

however, swimmers can often compete over multiple specialties or medleys. What would the force–velocity capacities of this multi-specialized athlete be like? Perhaps, the higher grade of cross-training among strokes could bring some sort of technical/bio-motor transfer, which trainers should purposely take advantage of in order to improve specific aspects of a single stroke. However, this speculation needs to be verified with apt experimental designs investigating possible changes in swimmers' maximum force–velocity exertion due to multifaceted training–competitive approaches.

5.5 Conclusions

Measuring maximum force–velocity exertion with the single pull-up test in regional-level swimmers may be a plain, scalable, lab-independent, cost-effective, and time-efficient experimental approach, apparently capable of discerning different levels of neuromuscular abilities based on stroke and distance specialization. However, it is debatable whether the results provided in this study are indeed a manifestation of different degrees of force–velocity capacities among distinctive categories of specialized swimmers, especially between sprinters and middle-distance swimmers, and between breaststroke and the other strokes. Therefore, we encourage continued investigation into this topic, to inform the process of developing evidence-based recommendations for scholars and trainers interested in enhancing swimming performance.

Finally, other sports could benefit from the evaluation of maximum force–velocity exertion for performance prediction and differentiation, especially closed-skill ones (as in swimming). This is because these kinds of sporting activities present almost no peer interactions and few environmental elements capable of affecting athletic performance, thus conceding sheer bio-motor abilities with considerable clout on the competitive outcome. However, it is also worth considering that swimming possesses many environmental elements that can affect performance and that differentiate it from other sports that are practiced on land in contrast to water. For these reasons, while the framework we proposed in this article could be incorporated within other sporting environments, it should also be rearranged for the specific sporting activity, with the ultimate goal of assessing and optimizing athletic performance for competitive endeavors.

6. Diving into Recovery. The Effects of Different Post-Competition Protocols for Enhancing Physio-Psychological Parameters in National Level Youth Swimmers

Abstract. The purpose of this study was to elucidate whether a specific approach regarding active swimming recovery could better promote psycho-physiological recovery right after competing in a high-level swimming race. To achieve this, we recruited 50 national level youth swimmers, randomly and equally assigning them to two groups, named “experimental” and “coach prescribed”. Each group performed a specific post-competition recovery protocol, consisting of different swimming paces, rest times, self-management of the exercises. We gathered data about blood lactate (BL), heart rate (HR), and rate of perceived exertion (RPE) at two different moments, the first moment right after the swimming competition (named post-competition phase), the second moment right after swimming the respective recovery protocol assigned (named post-recovery phase). A mixed MANOVA with Tukey HSD post-hoc analysis revealed no significant differences between the experimental and coach-prescribed groups in BL, HR, and RPE at the post-competition phase. At the post-recovery phase, however, the experimental group presented lower BL levels than the coach-prescribed group (2.40 ± 1.18 vs. 4.29 ± 2.07 mmol/L, $p < 0.05$). Finally, we found no interaction of swimming race ranking on recovery capacities. We conclude that for immediate improvement of BL in a wide range of high-level swimmers, an efficient recovery protocol should consist of several paces, high volumes, fixed and short rest times, whereas the widely popular self-managed, lower intensity approach does not seem as equally effective. Our study advances the development of novel recommendations for optimizing immediate fatigue management in competitive swimming.

6.1 Introduction

Swimming races involve maximum physio-psychological efforts from its participants, which can result in massive accumulation of metabolic waste products, dehydration, extreme rate of perceived exertion, and almost complete depletion of energy stores (Gonjo and Olstad, 2020). Consequently, the challenging demands of competitive clashes lead the athletes to experience peak levels of fatigue, as well as decreased performances for highly variable periods, which can last from minutes to even days (Kellmann et al., 2018). To mitigate these unavoidable issues, it is crucial to start the recovery process as soon as possible, particularly after competitive/highly intense endeavors (Poppendieck et al., 2013). In this regard, the aquatic medium has been revealed to be decisively influential in improving critical physiological parameters right after intense bouts of swimming. For instance, research has shown that after high-intensity sessions of swimming, recovery protocols performed in-water displayed higher rates of blood lactate removal than either passive recovery or land-based recovery (Ali Rasooli et al., 2012; Mota et al., 2017; Kostoulas et al., 2018). The higher efficiency of water-based protocols has been attributed to several factors. From a fluid-dynamic standpoint, the hydrostatic pressure of water provides external support to the body, which can enhance venous return and reduce pooling of blood in the lower extremities, ultimately allowing for better inter-exchange for H+ removal and faster metabolic recovery (Buchheit et al., 2010). Bearing this evidence in mind, swimmers have then been considerably advised to under-take active, swimming-based recovery protocols, rather than passive or land-based ones.

Nevertheless, when it comes to establish the optimal framework for designing efficient swimming recovery formats, several issues still need to be adequately ad-dressed within the scientific literature. One critical element concerns the lack of standardized protocols. That is, recovery protocols post-intense swimming are largely uncontrolled, being arbitrarily selected by athletes, coaches and/or governing bodies (Mota et al., 2017; Pollock et al., 2019; Faghy, Lomax and Brown, 2019). Although this approach may be respectful of the principle of training specificity and has shown to effectively reduce muscular fatigue to some extent, it relies heavily on the personal experience and present sensations of the single swimmer/swimming coach, thus exposing experimental and coaching designs to inter-variability fallacies and limitations. Furthermore, reported inconsistencies about the apt paces to sustain while swimming for post-race recovery purposes (Toubekis et al., 2006; Kostoulas et al., 2018; Pratama and Yimlamai, 2020) further suggest the need to develop more general recommendations for optimal parameters of intensity, volume, duration, and means to use, without basing entirely on the swimmers' self-perception.

To our knowledge, there are no studies in swimming that examine the effect of a specific recovery protocol after the competition on national youth swimmers. Bearing to this in mind, in the present study we investigated the effectiveness of two different active, water-based, post-competition recovery protocols for enhancing both physiological, i.e., capillary blood lactate (BL) and heart rate (HR), as well as psychological, i.e., rate of perceived exertion (RPE) indicators of fatigue, recruiting youth swimmers competing at the national level from 50m (sprinting) to 400m (middle-distance) races. One protocol, named "experimental", was designed by an experienced coach and the investigators from this research group, whereas the other protocol, defined as "coach-prescribed", sought to reflect coaches' habits and common practices in recovery-protocols prescriptions (Lomax, 2012; Pollock et al., 2019; Faghy et al., 2019). We hypothesize that the experimental approach would better enhance BL, HR, and RPE after the swimming race, compared to the coach-prescribed strategy. This was based on the following proposition. If in-water immersion causes increased cardiac output, in-creased blood flow, and subsequent nutrient and waste transportation through the system without increasing energy expenditure all while decreasing fatigue (Wilcock, Cronin and Hing, 2006) and if in-water active recoveries are more effective than passive in-water recovery in removing metabolic waste after intense swimming bouts (Toubekis, Douda and Tokmakidis, 2005; Toubekis et al., 2006; Mota et al., 2017), then the key towards optimizing recovery protocols has to be achieved by manipulation of the exercise variables, such as intensity, swimming paces, volume, rest between sets, etc. Considering this, it would then be sub-optimal to maintain a sole "steady" or "self-managing" swimming pace throughout the recovery session, because this strategy would likely miss on maximizing the beneficial physiological processes that elicits during swimming recovery. In the context of defining cardiac output, it is referred to as the volume of blood ejected by the heart per minute (measured in L/min). This process is essential for distributing blood throughout the body (Wilcock et al., 2006). High-intensity physical endeavors can significantly affect the body's demand for oxygen, subsequently leading to alterations in cardiac output. Cardiac output is regulated by two key factors: HR and stroke volume (SV). In fact, it is precisely calculated by multiplying HR and SV. The amount of blood ejected by the heart, where HR plays a central role, closely aligns with the body's overall metabolic requirements. Any deviations from the baseline cardiac output are directly proportional to changes in the body's oxygen needs, particularly during activities such as intense swimming. In situations of intense physiological stress, the cardiac output increases to ensure adequate blood supply to the body's tissues. This physiological response leads to an elevated HR (Wilcock et al., 2006), which we have utilized as a measure of physiological fatigue resulting from the strenuous demands of competitive swimming.

Furthermore, by leveraging on the fact that the experiment was conducted during an official, national swimming competition, we further investigated whether the swimmers with the best rankings also presented the highest recovery rates. This hypothesis was based on research already indicating that top ranked swimmers delivering the best race-times are stronger (Sorgente et al., 2023a), faster (Lopes et al., 2013)(Lopes et al., 2021), more powerful (Born et al., 2020), and in general, more prepared in physical and physiological instances than their lower-ranked opponents. Ultimately, this investigation would contribute to the existing body of knowledge by providing novel insights into the generalizability of immediate post-competition recovery protocols, with potential implications for upgrading the processes of fatigue management and consequent performance in competitive swimming.

6.2 Materials and Methods

6.2.1 Participants

A group of 50 young swimmers (25 females, 25 males) competing at the national level took part in the study (15 ± 1.1 years of age; height of 1.76 ± 0.02 m for males, 1.74 ± 0.02 m for females; weight of 67 ± 2.6 kg for males, 65 ± 2.8 kg for females; 8.5 ± 1.3 years of experience; 677 ± 22 Fédération Internationale De Natation points of best performance). All the swimmers competed in one swimming race, ranging from 50 and 100m (sprinters) to 200 and 400m (middle-distance) in one of the four strokes. The total sample was randomly and equally divided in two groups, one named “experimental” (13F, of which 6 sprinters and 7 middle-distance; 12M, 6 sprinters and 6 middle-distance), the other named “coach-prescribed” (12F, 6 sprinters and 6 middle-distance; 13M, of which 7 sprinters and 6 middle-distance). The athletes provided assent and their parents/guardians provided writ-ten informed consent after a detailed description of the study. The study was approved by the local Ethics Committee of the university (FGM02102019) and was conducted in accordance with the Declaration of Helsinki.

6.2.2 Set up, Tasks, Procedure

BL (mmol/L), HR (bpm) and RPE (0 - 10) levels were measured at two different moments. The first assessment occurred immediately after the completion of the swimming race post-swimming competition, called the post-competition phase. The second assessment occurred immediately after the completion of the assigned recovery protocol, called the post-recovery phase. On both occasions, the data was obtained right after the athlete came out of the swimming pool, i.e., +1 minute after maximal effort.

BL was withdrawn employing the finger-stick method and was measured using the Lactate Scout analyzer (SensLab GmbH, Germany) (Tanner, Fuller and Ross, 2010). HR was determined using the validated Polar Verity Sense optical heart rate sensor (Polar Electro Oy, Finland) (Schubert, Clark and De La Rosa, 2018). This sensor employs a time-based method to calculate averaged HRs over a predefined interval of 5 seconds. This “5 seconds interval" starts as soon as the sensor makes full contact with the subject's skin. The obtained average HR is then displayed on a smartphone or tablet application, aptly paired with the sensor via Bluetooth. To clarify, if the sensor was attached for approximately 50 seconds, the sensor would calculate and display ten averaged HR values in temporal succession, one for each 5 second interval. Concerning our study, in order to measure the HR closest to the experimental phases, we considered the average HR during the first 5 seconds after placing the sensor on the swimmer's skin. In other words, after the swimmer wore the HR sensor, we waited 5 seconds to then register the first number that was displayed on the tablet, representing the averaged HR during those initial 5 seconds. Since we conducted our experiment within an ecological and time-constrained context (i.e., during an official, national level swimming competition), this kind of functioning of the Polar Verity Sense sensor presented great advantages. That is, the 5-seconds time frame measurement allowed us to average out small fluctuations of the swimmers' HR, providing a more accurate representation of HR with-in the critical post-exertion time-window. On the contrary, a single value or a wider mean of HR could not capture these subtle yet significant fluctuations (Ali Rasooli et al., 2012; Schubert et al., 2018), especially after extremely intense cardiovascular efforts like swimming in a national level competition. Finally, the RPE was obtained by administering the Category-Ratio (0-10) RPE scale (BORGCR10) developed by Borg (Borg, 1954).

The official swimming races were held inside a regular, long-course (50 m) competitive swimming pool, whereas the experiments involving the recovery protocols took part inside another adjacent, short-course (25 m) swimming pool, which was in the same facility. When the swimmer finished the race, i.e., at the post-competition phase, the first evaluation of BL, HR, and RPE occurred. The athlete then moved to the short-course swimming pool, where the assigned recovery protocol was performed. Recovery protocols were swum entirely front crawl. After the athlete performed the designated recovery protocol, i.e., at the post-recovery phase, we measured again the BL, HR, and RPE, employing the same procedures as for the post-competition phase.

During congested periods of the competitive season, swimmers can take part in several races in a single event, e.g., competing in multiple individual races, re-lays, and/or medleys. In order to efficiently maximize psycho-physiological recovery, coaches are advised and encouraged to employ active swimming recovery protocols between races (Ali Rasooli et al., 2012; Mota et al., 2017; Kostoulas et al., 2018). Nevertheless, there are some discrepancies between the scientific and swimming communities regarding what type of swimming protocol would be fit for a better recovery and consequent preparation of the swimmers for their next races. Thus, the main difference between the two protocols here utilized reside mainly in the scientific support that the experimental protocol benefits of (Toubekis et al., 2006; Peinado et al., 2014; Hotfiel et al., 2019). Conversely, the coach-prescribed protocol was based on beliefs, habits, routines, and previous experience of swimming coaches. In fact, the coach-prescribed protocol was designed starting from previous works of other colleagues with swimming coaches (Mota et al., 2017; Pollock et al., 2019; Faghy et al., 2019), and then finalized in collaboration with the swimmers' coaches from our sample. This process was entirely supervised by the technical director of the swimming federation, which is also authoring this study. Both recovery protocols are described in Table 6.1.

Table 6.1. Description of the experimental and coach-prescribed swimming recovery protocols.

	Experimental	**Coach-prescribed ***
Activity	1 X 300-m: easy 2 X 50-m kick: first 10-m hard, last 15-m easy 6 X 50-m moderate, 20 sec rest between sets 4 X 25-m kick: moderate, 15 sec rest between sets 1 X 200-m: easy	1 X 200-m: steady 8 X 50-m: self-paced 2 X 100-m: easy
Total volume	1000 meters	800 meters
Total duration	20-25 min	15-25 min

* = Rest times were arbitrary. The terms "easy", "moderate", "hard", "steady" and "self-paced" all refer to the swimming pace that the performers had to maintain. The apt execution of each pace was supervised by the swimmers' federal technical director. This meant that when needed, swimmers were verbally encouraged to further adapt their pace according to the specific activity.

Confirming the gap between sport-science and swimming-coaching in this topic, the two protocols turned out rather diverse from each other. In particular, the experimental protocol presented a heterogeneous spectrum of exercises performed and materials utilized, e.g., the kickboard, other than a high variability of swimming intensities, both between and within exercises. Also, the experimental protocol presented a slightly higher volume and duration than the coach-prescribed protocol. Moreover, the rest times were carefully set in the experimental protocol, whereas in the coach-prescribed protocol, the rest times between swimming activities were left as "arbitrary". In general, the coach-prescribed protocol presented a much more "self-managing" approach to recovery, al-lowing swimmers a narrower and steadier intensity of swimming pace.

Regarding both protocols, we opted to provide the swimmers with qualitative information about stroke pacing (e.g., calling for "easy", "moderate", "hard" pacing). This would accommodate the personal tendencies of each swimmer, according to the principles of training adaptability. For this reason, each protocol duration fluctuated about 5 to 10 minutes. We would expect the experimental protocol to be more efficient in accelerating physiological recovery than a more "unfluctuating" and self-managing approach to active swimming recovery, i.e., the coach-prescribed protocol. That is because a more heterogeneous, high-variability, intensity-alternating, and carefully designed protocol (i.e., the experimental protocol) could better stimulate and support the body response to the hydrostatic pressure of the aquatic medium, hence providing faster metabolic recovery and ultimately making the swimmers readier to perform at their highest form in back-to-back competition settings. Contrarywise, limiting the ranges of swimming intensities and exercises, as well as not providing specific rest times between working sets, would reduce - or worse, subjectivize- the possibility of maximizing the aforementioned physiological processes that occur when swimming for recovery purposes., e.g., increased cardiac output and blood flow without increasing energy expenditure, subsequent nutrient and waste transportation through the system, etc.

*6.2.3 Handling Da*ta

Statistical analysis employed the Prism® 9.0.2 software (GraphPad Software, Inc., USA, 2021). Parametric analyses were conducted, as the Shapiro-Wilk test revealed a normal distribution of data ($p > 0.05$). First, in order to observe whether recovery parameters would differ based on sex, we conducted an independent sample t-test comparing males' and females' BL, HR, and RPE, both post-competition and post-recovery phases. A MANOVA employing 2 fixed factors (ranking, recovery protocol) and 1 repeated factor (from post-competition to post-recovery phase) was conducted to determine whether there were differences between the experimental and coach-prescribed protocols in BL, HR, and RPE, either at the post-competition or post-recovery phases, as well as interactions with the ranking obtained in the respective swimming races. In the case of statistically significant results, post-hoc comparisons were conducted using the Tukey HSD test.

6.3 Results

No significant differences were found in BL, HR, and RPE levels between males and females for the two groups and across the two phases. This allowed us to consider the whole sample of subjects regardless of gender.

As it could be expected, the within subjects MANOVA indicated that there were significant effects of recovery protocols from the post-competition to the post-recovery phases, both within the experimental (Wilks' Lambda = 0.22; $F(3, 48) = 128$, $p < 0.05$) as well as the coach-prescribed protocols (Wilks' Lambda = 0.49; $F(3, 48) = 91$, $p < 0.05$). Post-hoc comparisons using the Tukey HSD test indicated that in both recovery protocols, the mean levels for BL (13.74 ± 2.30 vs. 2.40 ± 1.18 mmol/L for experimental; 14.00 ± 3.21 vs. 4.29 ± 2.07 mmol/L for coach-prescribed), HR (191.48 ± 15.50 vs. 104.16 ± 16.25 bpm for experimental; 191.32 ± 16.90 vs. 105.72 ± 14.06 bpm for coach-prescribed) and RPE (8.80 ± 0.82 vs. 2.16 ± 1.11 for experimental; 8.28 ± 0.54 vs. 2.08 ± 1.19 for coach prescribed) were significantly lower post-recovery phase than post-competition phase. This suggested that both protocols were indeed useful in decreasing levels of fatigue both from a physiological and a psychological standpoint.

Regarding the between-subjects' effects, the 2 fixed factors MANOVA for the post-competition phase revealed that there were no significant differences nor interaction of ranking and recovery protocol on the BL, HR, and RPE variables (Table 6.2). These results confirmed the homogeneity of the two groups and that the various competitions elicited similar levels of fatigue among all the swimmers, regardless if they were sprinters or middle-distance competitors.

Table 6.2. Between subject effects of the MANOVA followed by the Tukey HSD post-hoc test.

Between subject effects (experimental vs. coach-prescribed)						
Time	**Effect**	**Wilk's Λ**	**F**	**Hypothesis df**	**Error df**	**p**
Post-competition	Ranking	0.88	2.48	4	46	0.91
	Recovery protocol	0.75	3.91	4	46	0.12
	Ranking * recovery protocol	0.81	2.71	4	46	0.66

Time	Variables	F	Value	df	Error df	p
	Ranking	0.85	3.01	4	46	0.72
Post-recovery	Recovery protocol †	0.66	13.36	4	46	0.03
	Ranking * recovery protocol	0.69	8.11	4	46	0.09

Multiple comparisons

Time	Variables	Experimental (M ± SD)	Coach-prescribed (M ± SD)	SE	p	Lower (95% CI)	Upper (95% CI)
	BL †	2.40 ± 1.18	4.29 ± 2.07	0.48	0.02	0.96	2.82
Post-recovery	HR	104.16 ± 16.25	105.72 ± 14.06	4.3	0.48	- 6.86	9.98
	RPE	2.16 ± 1.11	2.08 ± 1.19	0.33	0.92	- 0.72	0.56

df = degrees of freedom; † = significant effect at the 0.05 level; M ± SD = mean ± standard deviation; SE = standard error; BL = blood lactate (mmol/L); HR = heart rate (bpm); RPE = rate of perceived exertion; CI = confidence interval.

There was no significant interaction effect of ranking obtained on recovery protocol. However, we found significant differences between recovery protocols in enhancing BL recovery. In particular, the Tukey HSD post-hoc indicated that the experimental protocol was significantly better at reducing BL levels compared to the coach-prescribed intervention.

The mean swimming race ranking was 13.4 ± 10.57 for the experimental group, 13.48 ± 10.85 for the coach-prescribed group. There were 13 top-ten placements within the experimental group, collecting a total of 4 podiums (1 first place, 1 second place, 2 third places), whereas the coach-prescribed group had 15 top-ten placements with 4 podiums collected (1 first place, 3 second places, zero third places). The bottom-ranked places were at number 52 for the experimental group and number 69 for the coach-prescribed group. However, the between-subjects MANOVA detected no significant interaction of ranking obtained based on the recovery protocol per-formed.

Despite the non-significant interaction effects, interesting results came from the between-groups analysis regarding the post-recovery phase. Specifically, we found significant differences between recovery protocols on indicators of fatigue (Wilks' Lambda

= 0.66; $F (4, 46) = 13.36$, $p < 0.05$). Tukey HSD post-hoc indicated that the swimmers which performed the experimental protocol had significantly lower levels of BL (2.40 ± 1.18) compared to the swimmers performing the coach-prescribed protocol (4.29 ± 2.07 mmol/L), whereas the mean levels for HR (104 ± 16 vs. 106 ± 14 bpm) and RPE (2.16 ± 1.11 vs. 2.08 ± 1.19) did again present non-significant differences between groups (Figure 6.1).

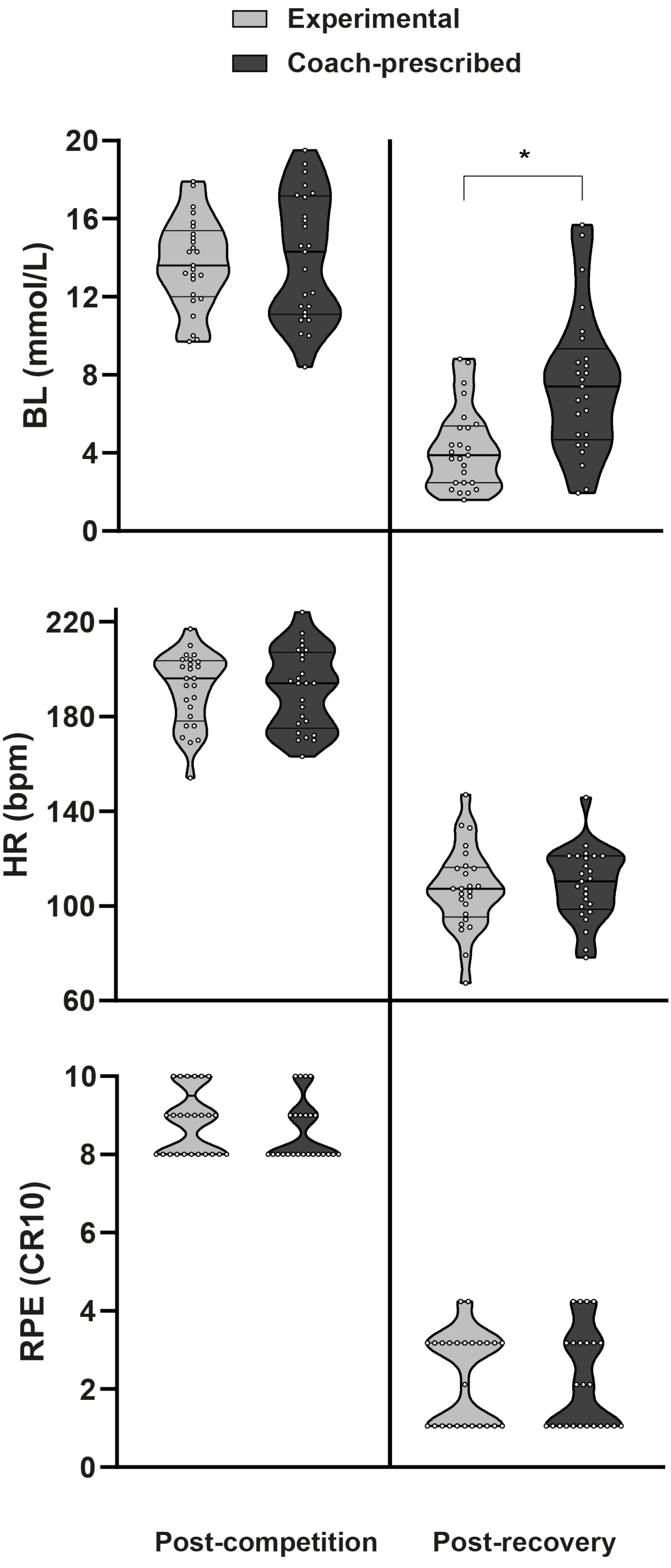

Figure 1. Violin plots comparing the experimental and coach-prescribed groups for BL, HR, and RPE, both post-competition (left side) and post-recovery phases (right side). As it shows, the only significant difference between the experimental and coach-prescribed group was found in BL levels

after having performed the relative recovery protocol. This outcome plainly displays that the experimental protocol employed in this study could be more effective than the coach-prescribed protocol in improving a precise parameter of the body's response to intense exercise, that is, BL.

* = statistically significant difference ($p < 0.05$) between the experimental and coach-prescribed groups.

6.4 Discussion

In this study, we sought to identify the optimal approach to enhance psycho-physiological recovery after a swimming race in national level youth swimmers. To achieve this, we compared the effects of two after-competition protocols on BL, HR, and RPE levels. Secondly, we also investigated whether higher-ranked swimmers would also present higher rates of recovery than the rest of their competitors.
In fact, although post exercise HR can adequately represent cardiovascular fatigue for a single group, the individual variation is too wide for this to be a useful measurement while being subject to external stimuli and comparing for different interventions (Bassey, 1996). Furthermore, despite the RPE being indicated as an eco-logical and valid tool to assess and quantify loads in swimming (Wallace, Slattery and Coutts, 2009), some issues when comparing interventions could reside in the fact that it remains a subjective scale, and that asking to quantify fatigue from 0 to 10 could "flatten out" the outcomes of an inquiry conducted with high level athletes competing at the same level, as it happened in the present study.

Nonetheless, BL was the only parameter which re-turned significant differences between the experimental and coach-prescribed group at the post-recovery phase. In particular, the experimental group presented significant lower levels of BL compared to the coach-prescribed group. Hence, we do not recommend employing exclusively HR and RPE when comparing short-term interventions to enhance recovery in high level swimmers, since the possible difference between groups appears to be excessively subtle for these two kinds of measures. Instead, in line with previous investigations, we suggest using HR (Koenig et al., 2014; Ganzevles et al., 2017) and RPE (Wallace et al., 2009; Czelusniak, Favreau and Ives, 2021) as tools to repeatedly test the single group/swimmer over a longer time span, being useful to assess cardiovascular as well as psychological progresses across the whole competitive season.

As noted earlier, interesting results came from the BL levels analysis, i.e., the experimental protocol made the swimmers recover more quickly than the coach-prescribed protocol. In consideration of our outcomes, we then suggest scholars and coaches interested in enhancing swimmers' anaerobic recovery to follow the conceptual foundation of the experimental protocol, i.e., designing in-water, active recovery protocols which range from an easy to a moderate pace, vary rest times, exercises, and materials used, all while not shying away from requesting the swimmers to go at their hardest pace, perhaps for short distances. Our recommendation, however, is in contrast with Lomax (Lomax, 2012), which found that after intense swimming, a recovery protocol consisting of self-paced, continuous steady rate swimming is equally effective in lowering BL levels than a swimming recovery consisting of various strokes, intensities, and rest intervals. The protocols used by these investigators was simi-lar to the coach-prescribed protocol employed in this study. However, it is worth noting that the colleagues recruited regional level swimmers (whereas we recruited national level youth swimmers), also employing the 200m race-paced front crawl in a controlled environment to elicit fatigue. Moreover, there is a compelling element of diversity (i.e., swimming race vs. controlled environment) that well highlights the particularity of our experiment compared to other investigations in the topic (Toubekis et al., 2008; Ali Rasooli et al., 2012; Pratama and Yimlamai, 2020). Mainly, we based on previous works which suggested that swimming performance measurements could have important implications within a competition setting (Faghy et al., 2019; Shell et al., 2020). Reasonably, the competitive environment already stimulated and motivated the swimmers to perform at their highest level, thus producing "actual" maximum levels of overall fatigue. It would be of interest to test whether our results could be replicated in a more controlled and less stressful environment, or if the competition setting is instead necessary for specific protocols to significantly arouse enhanced recovery from exercise-related fatigue.

Some parameters of physical conditioning were shown to be able to predict swimming performance among youth swimmers, i.e., maximum force-velocity exertion (Sorgente et al., 2023a) and mechanics (Pérez-Olea et al., 2018) in the pull-up motion, as well as overall upper (Lopes et al., 2013) and lower limb (Crowley et al., 2018) maximum strength capacities. Considering the closed-skill nature swimming, it is thus widely recognized that the most performing swimmers normally correspond to the most physically accomplished (Bravi et al., 2022). However, recovery capacities do not appear to follow the same trend. Specifically, the MANOVA we implemented resulted in no significant interactions of recovery protocols on indicators of fatigue when controlling for race ranking obtained. Thus, we cannot consider BL, HR, RPE, as valuable indicators nor predictors for swimming performance when comparing different recovery protocols. Notwithstanding, this could also mean that the recovery protocols here employed equally contributed to enhance recovery parameters regardless of the differences in achieved ranking by each swimmer. However, more focused, carefully designed studies should be con ducted to confirm this assertion, e.g., by assessing multiple, heterogeneous groups of swimmers competing at different levels.

Surely, some elements from our experimental de-sign could be ameliorated. For instance, we gathered the data at a specific time of the competitive season, which should supposedly be at the peak form of each athlete. However, we did not control any aspect of training in preparation to the competition. Therefore, dedicated re-search should focus on collecting the fluctuations and changes of physiological indicators of fatigue, especially BL, before and after swimming race/recovery protocols throughout the season.

Furthermore, it is worth noting that we opted for a higher (and unexplored) ecological value for this study, i.e., measuring BL, HR, and RPE during a national-level swimming event. This also meant operating at high temporal efficiencies due to the tight schedule of the competitions. For these reasons, we chose to only collect one BL measurement, and a 5-seconds average of the HR, per subject (for each phase). These kind of procedures for BL and HR assessment have been already used and standardized by other scholars (Tanner et al., 2010; Schubert et al., 2018); hence, they can be indeed telling of the physiological amount of fatigue elicited in swimmers after maxing out their performance. On the other hand, seeing that the lactate peak could subjectively occur at different times after maximal/supramaximal efforts, taking only one measurement may not be as accurate as considering, for instance, the lactate kinetic, which in turn would be more time-consuming. Consequently, the same could be stated concerning the employment of various HR measurements, where maximal HR during a specific time period, the R-R interval, or the HR kinetic could be used or combined in lieu of our approach. However, further research is required to test whether different kinds of BL and HR detection could bring significantly different result from one to an-other, in the ecological context of high-level swimming races. In other words, the present experimental approach regarding the strategies of BL and HR data collection holds some limitations. One is that, by standardizing the timing of our data collection, we ruled out paramount inter-subjective differences. The other one is that, by offering only a “snapshot” about the swimmers’ physio-logical levels of stress after competition and their respective recovery after the protocols here proposed, more accurate (thus more time-consuming) assessments of these parameters could bring different results than the ones we found with this experimental design. Because of these factors, it is important to state that there is an inherent (although systemic) limitation in our study, and that the interpretation of our results should be approached with caution.

Nevertheless, a recent work conducted by (Mavroudi et al., 2023) found the lactate peak after different all-out swimming sprints (25m, 35m, and 50m) occurring after 2 minutes from the trial. This is rather compelling, given that the lactate peak is usually thought to occur between 4 and 10 minutes after a maximal physical effort. While only partially confirming our approach, this suggests that systematizing and standardizing the timing of BL collection could be practical in detecting common trends in BL behavior after intense bout of swimming, as well as the BL response to a certain type of recovery protocol from these exertions, in spite of the individual differences between athletes.

Another critical element could pertain to the duration of the recovery protocols here employed, i.e., 20 minutes circa, which was fixed regardless of the distance specialization. Surely, it would be expected to design dedicated recovery protocols for sprinters and for middle-distance swimmers, given that the shorter the event is, the longer a swimmer should cool down (Riewald, 2015). This is because the intensity of the swimming bout determines how high blood lactate concentration will rise (Neric et al., 2009). For these reasons, sprinters can produce higher lactate concentrations than endurance athletes do, needing more time to clear lactate from their bodies (Issurin, 2010). However, we argue that there is an ante-cedent pitfall in swimming performance science. That is, usual recovery times employed for high-level swimmers do not continuously last more than 5-10 minutes (Toubekis et al., 2008). Other scholars pointed out that more time would be advisable. For instance, Riewald suggested that a general proper recovery protocol should consist of at least 15 minutes of active swimming, based on the fact that the lactate concentration rises over the first several minutes after the race, then, over the next 20 to 30 minutes, this concentration declines to near baseline or pre-race levels (Riewald, 2015). The decrement in fatigue between these 20 to 30 minutes happens for any kind of swimmer, regardless if they are sprinters or middle-distance specialists. Hence, leveraging on the latter notion, we opted for a generalized, systematic, and "no-rush" approach for all the swimmers involved, regardless of the distance specialization. Furthermore, despite the differences about lactate characteristics in distance and gender documented in (Holfelder, Brown and Bubeck, 2013), our results highlighted the importance of a recovery protocol employing a relatively large volume (around 1000 meters) and different intensities for a suitable and generally feasible fatigue dissipation, without considering the event or gender in which the swimmer has competed. In such wise, given that BF, HR and RPE levels did not differ within our two respective groups, this study revealed no differences in recovery capacities between sprinters and middle-distance swimmers, as well as among the four strokes. This would be beneficial for the generalizability aspect of these recovery protocols, which could lead to an even more efficient degree of control and comparison of the swimmers' specialization profiles, regarding both the specific stroke and distance expertise. It remains to be seen, however, whether our recommended experimental protocol could be time-optimized for endurance swimmers as well, such as open water swimmers or long-distance ones (i.e., swimmers specialized in 800m and 1500m races).

Specific age-category or gender differences should be taken into account when discussing the implementation of optimal after-competition recovery protocols. Regarding age, it is worth stressing that for the present study we only recruited national level swimmers competing at the junior level, i.e., the mean age was of 15 ± 1.1 years. Research in the topic of swimming recovery has focused on either elite (Vescovi, Falenchuk and Wells, 2011; Ali Rasooli et al., 2012; Faghy et al., 2019), master (Reaburn and Mackinnon, 1990), collegiate (Pratama and Yimlamai, 2020) or regional level swimmers (Lomax, 2012; Sorgente et al., 2023a), with many others referring to competitive/well-trained swimmers without further specifications (Wakayoshi et al., 1992; Buchheit et al., 2010; Kabasakalis et al., 2020). From a competitive standpoint, however, national level youth swimmers represent the most promising category for leveling up at the elite of the sport (Mitchell et al., 2021), making this specific age-level population worth of dedicated investigation. Nevertheless, we did not make any comparison between age-categories, e.g., senior vs. junior, as it was not the purpose of our investigation. Thus, the results from this study should be read under a specific filter of age and competitive level. It remains to be seen whether and how the approach used in this study would be effective for elder categories of swimmers, also considering the different training demands that comes with further progression in the sporting career.

Concerning the gender comparison, possible differences between males and females swimming performances have been explained due to physiological, psychological, anthropometrical and biomechanical aspects (Knechtle et al., 2020). In contrast with this review, however, we did not find differences in BL nor HR or RPE between male and female competitors. To this regard, it is worth noting that Rascon et al. reported that RPE and BL did not differ between genders in determining exercise intensity response, while females had higher HR than males (Rascon et al., 2020). Thus, our results are partially in line with previous research which stated that BL and RPE are gen-der-independent markers of physical exertion (Korhonen, Suominen and Mero, 2005). Thus, the approach here used towards immediate recovery post-competition appears to function regardless of the gender. However, the extent and robustness of this finding should be better investigated with dedicated research about differences in recovery rates between male and female swimmers.

6.5 Conclusions

In conclusion, we suggest that for improving BL levels, an optimal after-competition swimming recovery protocol should dictate precise iterations of the exercise variables, such as diversity of paces (even a hard one, but only for short distances), relatively high volumes, fixed and short rest times, a wide use of different exercises.

It is also worth noting that this investigation was conducted employing reliable, quick, simple, quasi non-invasive, and portable validated instrument, in a scalable and laboratory-free approach. Therefore, we encourage any swimming coach to take advantage of the present experimental design when fine-tuning strategies to enhance fatigue-disposal mechanisms in their athletes. Such knowledge would grant a better understanding to swimmers, their teams and interested scholars about which kind of conceptual framework to adopt when designing after-competition recovery protocols, with the ultimate purpose of optimizing and accelerating paramount physio-logical recovery pathways.

7. General conclusions

Delving into this thesis, it should be evident that progression in kinesiology research in young populations still necessitates a series of iterative endeavors and diverse methodologies before achieving substantive consolidation. The overarching goal of attaining "efficiency", as implied herein, especially pertains to the optimization of experimental practices. This refers to the fact that the manifold benefits of enhancing movement proficiency extend beyond the confines of mere improved motor output, to only seemingly unrelated domains. As argued above, these concepts are notably pertinent in the context of developmental age and youth individual sport performance. The integration of linear and non-linear approaches, favoring both specific (motor) and transversal (cognitive, physiological, self-perceptive) learnings, represents a pivotal aspect in improving the motor skills and performances discussed in this dissertation. From the developmental standpoint, this would prepare children for a rapidly changing society that requires them to expand their critical thinking, psychophysical energy, and psycho-emotional capacity to self-manage uncertainty. From the performative standpoint, this would lead athletes to reach the peak of their physical skills and achieve their maximum potential.

The integration of fine motor skills and visual instructions in children (Chapters 2 and 3), and force-velocity-recovery characteristics (Chapters 4, 5, 6) for athletes, heavily comes into play in further understanding and optimizing both general and highly specialized motor performances. This matrix of learning content from varied disciplinary domains represents a valuable (yet still overlooked) opportunity for a crucial transition in how we currently design, conduct, and analyze kinesiology research.

This scientific journey is characterized by a commitment to refinement and an unwavering dedication to bridging the gap between laboratory research and "real-world" applicability. It is the hope of the author that the endeavor represented by this thesis would not only mark as a stride, but would also serve as a catalyst, propelling the academic community towards the fulfillment of the transformative potential of kinesiology research in on-field contexts. In this way, it would be possible to open avenues for comprehensive interventions and targeted strategies that would finally evolve beyond the immediate scope of traditional kinesiological inquiries. Through "efficiency", we pave the way for interventions that surpass the traditional boundaries of kinesiological inquiries, contributing to the comprehensive development of individuals and athletes alike in a world that demands both physical prowess and mental resilience.

References

Aadland, K.N., Moe, V.F., Aadland, E., Anderssen, S.A., Resaland, G.K. and Ommundsen, Y. (2017) Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children. *Mental Health and Physical Activity* **12**, 10–18.

Agar, C., Humphries, C.A., Naquin, M., Hebert, E. and Wood, R. (2016) Does Varying Attentional Focus Affect Skill Acquisition in Children? A Comparison of Internal and External Focus Instructions and Feedback. *The Physical Educator* **73**, 639–651.

Albuquerque, M.R., Rennó, G.V.C., Bruzi, A.T., Fortes, L. de S. and Malloy-Diniz, L.F. (2021) Association between motor competence and executive functions in children. *Applied Neuropsychology: Child*, 1–9.

Ali Rasooli, S., Koushkie Jahromi, M., Asadmanesh, A. and Salesi, M. (2012) Influence of massage, active and passive recovery on swimming performance and blood lactate. *Journal of Sports Medicine and Physical Fitness* **52**.

Allen, K.A., Bredero, B., Van Damme, T., Ulrich, D.A. and Simons, J. (2017) Test of Gross Motor Development-3 (TGMD-3) with the Use of Visual Supports for Children with Autism Spectrum Disorder: Validity and Reliability. *Journal of Autism and Developmental Disorders* **47**, 813–833.

Amaro, N.M., Marinho, D.A., Marques, M.C., Batalha, N.P. and Morouço, P.G. (2017) Effects of Dry-Land Strength and Conditioning Programs in Age Group Swimmers. *Journal of Strength and Conditioning Research* **31**, 2447–2454.

Aspenes, S.T. and Karlsen, T. (2012) Exercise-Training Intervention Studies in Competitive Swimming. *Sports Medicine* **42**, 527–543.

Bachero-Mena, B., Pareja-Blanco, F. and González-Badillo, J.J. (2021) Effects of Resistance Training on Physical Performance in High-Level 800-Meter Athletes: A Comparison Between High-Speed Resistance Training and Circuit Training. *Journal of Strength and Conditioning Research* **35**, 1905–1915.

Balasubramanian, S., Melendez-Calderon, A., Roby-Brami, A. and Burdet, E. (2015) On the analysis of movement smoothness. *Journal of NeuroEngineering and Rehabilitation* **12**.

Bandeira, P.F.R., Duncan, M., Pessoa, M.L., Soares, Í., da Silva, L., Mota, J., et al. (2020) TGMD-2 Short Version: Evidence of Validity and Associations With Sex, Age, and BMI in Preschool Children. *Journal of Motor Learning and Development* **8**, 528–543.

Banyard, H.G., Tufano, J.J., Weakley, J.J.S., Wu, S., Jukic, I. and Nosaka, K. (2021) Superior Changes in Jump, Sprint, and Change-of-Direction Performance but Not Maximal Strength Following 6 Weeks of Velocity-Based Training Compared With 1-Repetition-Maximum Percentage-Based Training. *International Journal of Sports Physiology and Performance* **16**, 232–242.

Barbosa, T., Fernandes, R., Keskinen, K., Colaço, P., Cardoso, C., Silva, J., et al. (2006) Evaluation of the Energy Expenditure in Competitive Swimming Strokes. *International Journal of Sports Medicine* **27**, 894–899.

Bassey, E.J. (1996) Postexercise heart rates and pulse palpation as a means of determining exercising intensity in an aerobic dance class. *British Journal of Sports Medicine* **30**.

Bekkering, H., Wohlschläger, A. and Gattis, M. (2000) Imitation of Gestures in Children is Goal-directed. *The Quarterly Journal of Experimental Psychology Section A* **53**, 153–164.

Benjaminse, A., Welling, W., Otten, B. and Gokeler, A. (2018) Transfer of improved movement technique after receiving verbal external focus and video instruction. *Knee Surgery, Sports Traumatology, Arthroscopy* **26**, 955–962.

Berryman, N., Mujika, I. and Bosquet, L. (2019) Concurrent Training for Sports Performance: The 2 Sides of the Medal. *International Journal of Sports Physiology and Performance* **14**, 279–285.

Blank, R., Miller, V., Von Voß, H. and Von Kries, R. (1999) Effects of age on distally and proximally generated drawing movements: A kinematic analysis of school children and adults. *Developmental Medicine and Child Neurology* **41**.

Bolger, L.E., Bolger, L.A., O' Neill, C., Coughlan, E., O'Brien, W., Lacey, S., et al. (2018) Age and Sex Differences in Fundamental Movement Skills Among a Cohort of Irish School Children. *Journal of Motor Learning and Development* **6**, 81–100.

Bompa, T.O. and Buzzichelli, C.A. (2019) *Periodization: Theory and Methodology of Training*. Human Kinetics.

Borg, G.A.V. (1954) Psychophysical bases of perceived exertion. *Plastic and Reconstructive Surgery* **14**.

Born, D.-P., Stöggl, T., Petrov, A., Burkhardt, D., Lüthy, F. and Romann, M. (2020) Analysis of Freestyle Swimming Sprint Start Performance After Maximal Strength or Vertical Jump Training in Competitive Female and Male Junior Swimmers. *Journal of Strength and Conditioning Research* **34**, 323–331.

Bravi, R., Gavazzi, G., Benedetti, V., Giovannelli, F., Grasso, S., Panconi, G., et al. (2022) Effect of different sport environments on proactive and reactive motor inhibition: A study on open- and closed-skilled athletes via mouse-tracking procedure. *Frontiers in Psychology* **13**.

Bravi, R., Ioannou, C.I., Minciacchi, D. and Altenmüller, E. (2019) Assessment of the effects of Kinesiotaping on musical motor performance in musicians suffering from focal hand dystonia: a pilot study. *Clinical Rehabilitation* **33**, 1636–1648.

Buchheit, M., Al Haddad, H., Chivot, A., Leprêtre, P.M., Ahmaidi, S. and Laursen, P.B. (2010) Effect of in- versus out-of-water recovery on repeated swimming sprint performance. *European Journal of Applied Physiology* **108**, 321–327.

Burns, R.D., Fu, Y., Hannon, J.C. and Brusseau, T.A. (2017) School Physical Activity Programming and Gross Motor Skills in Children. *American Journal of Health Behavior* **41**, 591–598.

Burton, A.W. and Rodgerson, R.W. (2001) New Perspectives on the Assessment of Movement Skills and Motor Abilities. *Adapted Physical Activity Quarterly* **18**, 347–365.

Cameron, C.E., Brock, L.L., Murrah, W.M., Bell, L.H., Worzalla, S.L., Grissmer, D., et al. (2012) Fine Motor Skills and Executive Function Both Contribute to Kindergarten Achievement. *Child Development* **83**.

Cameron, C.E., Cottone, E.A., Murrah, W.M. and Grissmer, D.W. (2016) How Are Motor Skills Linked to Children's School Performance and Academic Achievement? *Child Development Perspectives* **10**, 93–98.

Carvalho, D.D., Soares, S., Zacca, R., Marinho, D.A., Silva, A.J., Pyne, D.B., et al. (2019) In-water and on-land swimmers' symmetry and force production. *International Journal of Environmental Research and Public Health* **16**.

Catmur, C. and Heyes, C. (2019) Mirroring 'meaningful' actions: Sensorimotor learning modulates imitation of goal-directed actions. *Quarterly Journal of Experimental Psychology* **72**, 322–334.

Chen, J., Kwok, A.P.K. and Li, Y. (2023) Effects of expertise in skill-oriented sports on postural control: An event-related potential study using dual-task paradigm. *Neuroscience Letters* **812**, 137408.

Cohen, E.J., Bravi, R., Bagni, M.A. and Minciacchi, D. (2018a) Precision in drawing and tracing tasks: Different measures for different aspects of fine motor control. *Human Movement Science* **61**, 177–188.

Cohen, E.J., Bravi, R. and Minciacchi, D. (2018b) The effect of fidget spinners on fine motor control. *Scientific Reports* **8**, 3144.

Cohen, E.J., Bravi, R. and Minciacchi, D. (2021) Assessing the Development of Fine Motor Control in Elementary School Children Using Drawing and Tracing Tasks. *Perceptual and Motor Skills* **128**, 605–624.

Cohen, K., Lubans, D., Morgan, P., Plotnikoff, R. and Callister, R. (2014) Improving fundamental movement skill competency among children attending schools in low-income communities: The SCORES cluster RCT. *Journal of Science and Medicine in Sport* **18**, e12.

Cormie, P., McGuian, M.R. and Newton, R.U. (2010) Adaptations in Athletic Performance after Ballistic Power versus Strength Training. *Medicine & Science in Sports & Exercise* **42**, 1582–1598.

Costa, M.J., Balasekaran, G., Vilas-Boas, J.P. and Barbosa, T.M. (2015) Physiological Adaptations to Training in Competitive Swimming: A Systematic Review. *Journal of Human Kinetics* **49**, 179–194.

Cronin, J.B. and Templeton, R.L. (2008) Timing Light Height Affects Sprint Times. *Journal of Strength and Conditioning Research* **22**, 318–320.

Crowley, E., Harrison, A.J. and Lyons, M. (2018) Dry-Land Resistance Training Practices of Elite Swimming Strength and Conditioning Coaches. *Journal of Strength and Conditioning Research* **32**, 2592–2600.

Czelusniak, O., Favreau, E. and Ives, S.J. (2021) Effects of Warm-Up on Sprint Swimming Performance, Rating of Perceived Exertion, and Blood Lactate Concentration: A Systematic Review. *Journal of Functional Morphology and Kinesiology* **6**, 85.

Dayem, T.S.A.E.-, Salem, E.E. and Hadidy, E.I.E.- (2015) Correlation between Gross Motor Activities and Hand Writing Skills in Elementary School Children. *Trends in Applied Sciences Research* **10**, 259–269.

Dehghan, L., Mirzakhani, N., Rezaee, M. and Tabatabaee, M. (2017) The relationship between fine motor skills and social development and maturation. *Iranian Rehabilitation Journal* **15**.

Dorn, T.W., Schache, A.G. and Pandy, M.G. (2012) Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance. *Journal of Experimental Biology* **215**, 1944–1956.

Dorrell, H.F., Smith, M.F. and Gee, T.I. (2020) Comparison of Velocity-Based and Traditional Percentage-Based Loading Methods on Maximal Strength and Power Adaptations. *Journal of Strength and Conditioning Research* **34**, 46–53.

Duchateau, J., Stragier, S., Baudry, S. and Carpentier, A. (2021) Strength Training: In Search of Optimal Strategies to Maximize Neuromuscular Performance. *Exercise and Sport Sciences Reviews* **49**, 2–14.

Duncan, M.J., Jones, V., O'Brien, W., Barnett, L.M. and Eyre, E.L.J. (2018) Self-Perceived and Actual Motor Competence in Young British Children. *Perceptual and Motor Skills* **125**, 251–264.

Dundar, A., Kocahan, S. and Arslan, C. (2019) Effects of different loading exercises on apelin levels and physical and hematologic parameters of swimmers. *Hormone Molecular Biology and Clinical Investigation* **38**.

Eldred, K. and Darrah, J. (2010) Using cluster analysis to interpret the variability of gross motor scores of children with typical development. *Physical Therapy* **90**.

Emanuel, M., Jarus, T. and Bart, O. (2008) Effect of Focus of Attention and Age on Motor Acquisition, Retention, and Transfer: A Randomized Trial. *Physical Therapy* **88**, 251–260.

Escolano-Pérez, E., Herrero-Nivela, M.L. and Losada, J.L. (2020) Association Between Preschoolers' Specific Fine (But Not Gross) Motor Skills and Later Academic Competencies: Educational Implications. *Frontiers in Psychology* **11**.

Faghy, M.A., Lomax, M. and Brown, P.I. (2019) Active recovery strategy and lactate clearance in elite swimmers. *The Journal of Sports Medicine and Physical Fitness* **59**.

Fathi Khatab, S., Ghasemi, A. and Mousavi Sadati, S.K. (2018) The Effect of Focus Instructions on Dart Throwing Performance in Children With and Without Developmental Coordination Disorder. *Annals of Applied Sport Science* **6**, 55–60.

van der Fels, I.M.J., te Wierike, S.C.M., Hartman, E., Elferink-Gemser, M.T., Smith, J. and Visscher, C. (2015) The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. *Journal of Science and Medicine in Sport* **18**, 697–703.

Fernandes, V.R., Ribeiro, M.L.S., Melo, T., de Tarso Maciel-Pinheiro, P., Guimarães, T.T., Araújo, N.B., et al. (2016) Motor Coordination Correlates with Academic Achievement and Cognitive Function in Children. *Frontiers in Psychology* **7**.

Flatters, I., Mushtaq, F., Hill, L.J.B., Rossiter, A., Jarrett-Peet, K., Culmer, P., et al. (2014) Children's head movements and postural stability as a function of task. *Experimental Brain Research* **232**.

Foti, F., Piras, F., Vicari, S., Mandolesi, L., Petrosini, L. and Menghini, D. (2019) Observational Learning in Low-Functioning Children With Autism Spectrum Disorders: A Behavioral and Neuroimaging Study. *Frontiers in Psychology* **9**.

Ganzevles, S.P.M., de Haan, A., Beek, P.J., Daanen, H.A.M. and Truijens, M.J. (2017) Heart-Rate Recovery After Warm-up in Swimming: A Useful Predictor of Training Heart-Rate Response? *International Journal of Sports Physiology and Performance* **12**, 742–748.

Garrido, N., Marinho, D.A., Reis, V.M., van den Tillaar, R., Costa, A.M., Silva, A.J., et al. (2010) Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? *Journal of Sports Science and Medicine* **9**.

Geertsen, S.S., Thomas, R., Larsen, M.N., Dahn, I.M., Andersen, J.N., Krause-Jensen, M., et al. (2016) Motor Skills and Exercise Capacity Are Associated with Objective Measures of Cognitive Functions and Academic Performance in Preadolescent Children. *PLOS ONE* **11**, e0161960.

Gonjo, T., Narita, K., McCabe, C., Fernandes, R.J., Vilas-Boas, J.P., Takagi, H., et al. (2020) Front Crawl Is More Efficient and Has Smaller Active Drag Than Backstroke Swimming: Kinematic and Kinetic Comparison Between the Two Techniques at the Same Swimming Speeds. *Frontiers in Bioengineering and Biotechnology* **8**.

Gonjo, T., Njøs, N., Eriksrud, O. and Olstad, B.H. (2021) The Relationship Between Selected Load-Velocity Profile Parameters and 50 m Front Crawl Swimming Performance. *Frontiers in Physiology* **12**.

Gonjo, T. and Olstad, B.H. (2020) Race Analysis in Competitive Swimming: A Narrative Review. *International Journal of Environmental Research and Public Health* **18**, 69.

Gontarev, S., Zivkovic, V., Velickovska, L.A. and Naumovski, M. (2014) First normative reference of standing long jump indicates gender difference in lower muscular strength of Macedonian school children. *Health* **06**, 99–106.

González Ravé, J.M. (2021) The traditional periodization in individual sports: providing effective responses to both new and old problems. *Archivos de Medicina del Deporte* **38**, 76–77.

González-Badillo, J.J. and Sánchez-Medina, L. (2010) Movement Velocity as a Measure of Loading Intensity in Resistance Training. *International Journal of Sports Medicine* **31**, 347–352.

González-Ravé, J.M., B. Pyne, D., Castillo, J., González-Mohíno, F. and Stone, M. (2022) Training periodization for a world-class 400 meters individual medley swimmer. *Biology of Sport* **39**, 883–888.

Griffiths, A., Toovey, R., Morgan, P.E. and Spittle, A.J. (2018) Psychometric properties of gross motor assessment tools for children: a systematic review. *BMJ Open* **8**, e021734.

Guadagnoli, M.A. and Lee, T.D. (2004) Challenge Point: A Framework for Conceptualizing the Effects of Various Practice Conditions in Motor Learning. *Journal of Motor Behavior* **36**, 212–224.

Guest, L., Balogh, R., Dogra, S. and Lloyd, M. (2017) Examining the Impact of a Multi-Sport Camp for Girls Ages 8–11 With Autism Spectrum Disorder. *Therapeutic Recreation Journal* **51**, 109–126.

Gulde, P. and Hermsdörfer, J. (2018) Smoothness Metrics in Complex Movement Tasks. *Frontiers in Neurology* **9**.

Haibach, P.S., Collier, D.H. and Reid, G. (2011) *Motor Learning and Development*.

Halperin, I. (2018) Case Studies in Exercise and Sport Sciences: A Powerful Tool to Bridge the Science–Practice Gap. *International Journal of Sports Physiology and Performance* **13**, 824–825.

Haugen, T., McGhie, D. and Ettema, G. (2019) Sprint running: from fundamental mechanics to practice—a review. *European Journal of Applied Physiology* **119**, 1273–1287.

Haugen, T.A., Solberg, P.A., Foster, C., Morán-Navarro, R., Breitschädel, F. and Hopkins, W.G. (2018) Peak Age and Performance Progression in World-Class Track-and-Field Athletes. *International Journal of Sports Physiology and Performance* **13**, 1122–1129.

Hayes, S.J., Ashford, D. and Bennett, S.J. (2008) Goal-directed imitation: The means to an end. *Acta Psychologica* **127**, 407–415.

Haywood Kathleen M. and Getchell, N. (2005) *Life Span Motor Development.* , 4th edition. Champaing, IL, US: Human Kinetics.

Hebert, E. (2018) The Effects of Observing a Learning Model (or Two) on Motor Skill Acquisition. *Journal of Motor Learning and Development* **6**, 4–17.

Hermosilla, F., Sanders, R., González-Mohíno, F., Yustres, I. and González-Rave, J.M. (2021) Effects of Dry-Land Training Programs on Swimming Turn Performance: A Systematic Review. *International Journal of Environmental Research and Public Health* **18**, 9340.

Hermosilla, F., Yustres, I., Psycharakis, S., Santos del Cerro, J., González-Mohíno, F. and González-Rave, J.M. (2022) Which variables may affect underwater glide performance after a swimming start? *European Journal of Sport Science* **22**, 1141–1148.

Holfelder, B., Brown, N. and Bubeck, D. (2013) The Influence of Sex, Stroke and Distance on the Lactate Characteristics in High Performance Swimming. *PLoS ONE* **8**, e77185.

Holfelder, B. and Schott, N. (2014) Relationship of fundamental movement skills and physical activity in children and adolescents: A systematic review. *Psychology of Sport and Exercise* **15**, 382–391.

Hotfiel, T., Mayer, I., Huettel, M., Hoppe, M.W., Engelhardt, M., Lutter, C., et al. (2019) Accelerating Recovery from Exercise-Induced Muscle Injuries in Triathletes: Considerations for Olympic Distance Races. *Sports* **7**, 143.

Hraski, M., Hraski, Ž. and Prskalo, I. (2015) Comparison of standing long jump technique performed by subjects from different age groups. *Baltic Journal of Sport and Health Sciences* **3**, 2–12.

Hreljac, A. (2000) Stride smoothness evaluation of runners and other athletes. *Gait & Posture* **11**, 199–206.

Hughes, D.C., Ellefsen, S. and Baar, K. (2018) Adaptations to Endurance and Strength Training. *Cold Spring Harbor Perspectives in Medicine* **8**, a029769.

Ikuta, Y., Matsuda, Y., Yamada, Y., Kida, N. And Oda, S. (2010) Relationship Between Changes Of Swimming Velocity, Stroke Rate, Stroke Length And Muscle Activities In Front Crawl Swimming. *Japanese Journal of Physical Fitness and Sports Medicine* **59**, 427–438.

Issurin, V.B. (2010) New Horizons for the Methodology and Physiology of Training Periodization. *Sports Medicine* **40**, 189–206.

Jiménez-Reyes, P., Castaño-Zambudio, A., Cuadrado-Peñafiel, V., González-Hernández, J.M., Capelo-Ramírez, F., Martínez-Aranda, L.M., et al. (2021) Differences between adjusted vs. non-adjusted loads in velocity-based training: consequences for strength training control and programming. *PeerJ* **9**, e10942.

Jongbloed-Pereboom, M., Nijhuis-van der Sanden, M.W.G. and Steenbergen, B. (2013) Norm Scores of the Box and Block Test for Children Ages 3-10 Years. *American Journal of Occupational Therapy* **67**, 312–318.

Junaid, K.A. and Fellowes, S. (2006) Gender differences in the attainment of motor skills on the movement assessment battery for children. *Physical and Occupational Therapy in Pediatrics* **26**.

Kabasakalis, A., Nikolaidis, S., Tsalis, G. and Mougios, V. (2020) Response of Blood Biomarkers to Sprint Interval Swimming. *International Journal of Sports Physiology and Performance* **15**, 1442–1447.

Karlin, L. and Mortimer, R.G. (1962) Effects of visual and verbal cues on learning a motor skill. *Journal of Experimental Psychology* **64**, 608–614.

Kavanaugh, A. (2008) The role of progressive overload in sports conditioning. *Strength & conditioning journal* **15**.

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A.J., Duffield, R., et al. (2018) Recovery and Performance in Sport: Consensus Statement. *International Journal of Sports Physiology and Performance* **13**, 240–245.

Kiely, J., Pickering, C. and Collins, D.J. (2019) Smoothness: an Unexplored Window into Coordinated Running Proficiency. *Sports Medicine - Open* **5**, 43.

Kitsantas, A., Zimmerman, B.J. and Cleary, T. (2000) The role of observation and emulation in the development of athletic self-regulation. *Journal of Educational Psychology* **92**, 811–817.

Knechtle, B., Dalamitros, A.A., Barbosa, T.M., Sousa, C.V., Rosemann, T. and Nikolaidis, P.T. (2020) Sex Differences in Swimming Disciplines—Can Women Outperform Men in Swimming? *International Journal of Environmental Research and Public Health* **17**, 3651.

Koenig, J., Jarczok, M.N., Wasner, M., Hillecke, T.K. and Thayer, J.F. (2014) Heart Rate Variability and Swimming. *Sports Medicine* **44**, 1377–1391.

Komi, P. V. (1994) Strength and Power in Sport. *Medicine & Science in Sports & Exercise* **26**, 1422.

Korhonen, M.T., Suominen, H. and Mero, A. (2005) Age and Sex Differences in Blood Lactate Response to Sprint Running in Elite Master Athletes. *Canadian Journal of Applied Physiology* **30**, 647–665.

Kostoulas, I.D., Toubekis, A.G., Paxinos, T., Volaklis, K. and Tokmakidis, S.P. (2018) Active recovery intervals restore initial performance after repeated sprints in swimming. *European Journal of Sport Science* **18**, 323–331.

Kraemer, W.J. and Fragala, M.S. (2006) Personalize It. *ACSM's Health & Fitness Journal* **10**, 7–17.

Krajenbrink, H., van Abswoude, F., Vermeulen, S., van Cappellen, S. and Steenbergen, B. (2018) Motor learning and movement automatization in typically developing children: The role of instructions with an external or internal focus of attention. *Human Movement Science* **60**, 183–190.

Lai, S.K., Costigan, S.A., Morgan, P.J., Lubans, D.R., Stodden, D.F., Salmon, J., et al. (2014) Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies. *Sports Medicine* **44**.

Lee, T.D., Eliasz, K.L., Gonzalez, D., Alguire, K., Ding, K. and Dhaliwal, C. (2016) On the Role of Error in Motor Learning. *Journal of Motor Behavior* **48**, 99–115.

Leonard, H.C. and Hill, E.L. (2014) Review: The impact of motor development on typical and atypical social cognition and language: A systematic review. *Child and Adolescent Mental Health* **19**.

Li, L. and Smith, D.M. (2021) Neural Efficiency in Athletes: A Systematic Review. *Frontiers in Behavioral Neuroscience* **15**.

Lipkin, P.H. (2009) MOTOR DEVELOPMENT AND DYSFUNCTION. In: *Developmental-Behavioral Pediatrics*. Elsevier. 643–652.

Lloyd, M., Saunders, T.J., Bremer, E. and Tremblay, M.S. (2014) Long-Term Importance of Fundamental Motor Skills: A 20-Year Follow-Up Study. *Adapted Physical Activity Quarterly* **31**, 67–78.

Lomax, M. (2012) The Effect of Three Recovery Protocols on Blood Lactate Clearance After Race-Paced Swimming. *Journal of Strength and Conditioning Research* **26**, 2771–2776.

van der Loo, J., Krahmer, E. and van Amelsvoort, M. (2021) Learning How to Throw Darts. Effects of Modeling Type and Reflection on Novices' Dart-Throwing Skills. *Journal of Motor Behavior* **53**, 105–116.

Lopes, T.J., Neiva, H.P., Gonçalves, C.A., Nunes, C. and Marinho, D.A. (2021) The effects of dry-land strength training on competitive sprinter swimmers. *Journal of Exercise Science & Fitness* **19**, 32–39.

Lopes, L., Santos, R., Pereira, B. and Lopes, V.P. (2013) Associations between gross Motor Coordination and Academic Achievement in elementary school children. *Human Movement Science* **32**.

Loturco, I., D'Angelo, R.A., Fernandes, V., Gil, S., Kobal, R., Cal Abad, C.C., et al. (2015) Relationship Between Sprint Ability and Loaded/Unloaded Jump Tests in Elite Sprinters. *Journal of Strength and Conditioning Research* **29**, 758–764.

Luke, N. and Singh, N. (2018) Teaching Observational Learning to Children with Autism: Pedagogical Advancements for the Scientist-Practitioner. *International Journal of Pedagogy and Teacher Education* **2**, 319.

Lum, D. and Barbosa, T.M. (2019) Effects of Strength Training on Olympic Time-Based Sport Performance: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *International Journal of Sports Physiology and Performance* **14**, 1318–1330.

MacDonald, J. and Ahearn, W.H. (2015) Teaching observational learning to children with autism. *Journal of Applied Behavior Analysis* **48**, 800–816.

Magistro, D., Piumatti, G., Carlevaro, F., Sherar, L.B., Esliger, D.W., Bardaglio, G., et al. (2018) Measurement invariance of TGMD-3 in children with and without mental and behavioral disorders. *Psychological Assessment* **30**, 1421–1429.

Martens, J., Figueiredo, P. and Daly, D. (2015) Electromyography in the four competitive swimming strokes: A systematic review. *Journal of Electromyography and Kinesiology* **25**, 273–291.

Mathiowetz, V. (1985) Box and Blocks Test Instructions General Information (derived from Mathiowetz et al , 1985): *Am J Occup Ther.*

Mathiowetz, V., Federman, S. and Wiemer, D. (1985) Box and Block Test of Manual Dexterity: Norms for 6–19 Year Olds. *Canadian Journal of Occupational Therapy* **52**, 241–245.

Mavroudi, M., Kabasakalis, A., Petridou, A. and Mougios, V. (2023) Blood Lactate and Maximal Lactate Accumulation Rate at Three Sprint Swimming Distances in Highly Trained and Elite Swimmers. *Sports* **11**, 87.

McFee, G. (2013) Officiating in Aesthetic Sports. *Journal of the Philosophy of Sport* **40**, 1–17.

McKay, A.K.A., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., et al. (2022) Defining Training and Performance Caliber: A Participant Classification Framework. *International Journal of Sports Physiology and Performance* **17**, 317–331.

McKenzie, T.L., Sallis, J.F., Broyles, S.L., Zive, M.M., Nader, P.R., Berry, C.C., et al. (2002) Childhood Movement Skills: Predictors of Physical Activity in Anglo American and Mexican American Adolescents? *Research Quarterly for Exercise and Sport* **73**, 238–244.

Mitchell, L.A., Knight, C.J., Morris, R. and Mellalieu, S.D. (2021) “Maybe I’m just not good enough?”: British swimmers’ experiences of attempting to qualify for the Olympic Games. *Scandinavian Journal of Medicine & Science in Sports* **31**, 1558–1573.

Moore, I.S. (2016) Is There an Economical Running Technique? A Review of Modifiable Biomechanical Factors Affecting Running Economy. *Sports Medicine* **46**, 793–807.

Mota, M.R., Dantas, R.A.E., Oliveira-Silva, I., Sales, M.M., da Costa Sotero, R., Espíndola Mota Venâncio, P., et al. (2017) Effect of self-paced active recovery and passive recovery on blood lactate removal following a 200 m freestyle swimming trial. *Open Access Journal of Sports Medicine* **Volume 8**, 155–160.

Mujika, I., Halson, S., Burke, L.M., Balagué, G. and Farrow, D. (2018) An Integrated, Multifactorial Approach to Periodization for Optimal Performance in Individual and Team Sports. *International Journal of Sports Physiology and Performance* **13**, 538–561.

Muniz-Pardos, B., Gomez-Bruton, A., Matute-Llorente, A., Gonzalez-Aguero, A., Gomez-Cabello, A., Gonzalo-Skok, O., et al. (2019) Swim-Specific Resistance Training: A Systematic Review. *Journal of Strength and Conditioning Research* **33**, 2875–2881.

Muñoz de la Cruz, V., Agudo-Ortega, A., Sorgente, V., Turner, A.P. and González-Ravé, J.M. (2023) The effectiveness of adjusting resistance training loads through velocity-based techniques in experienced sprinters: a case series study. *Frontiers in Physiology* **14**.

Myszka, S., Yearby, T. and Davids, K. (2023) (Re)conceptualizing movement behavior in sport as a problem-solving activity. *Frontiers in Sports and Active Living* **5**.

Nadel, J., Aouka, N., Coulon, N., Gras-Vincendon, A., Canet, P., Fagard, J., et al. (2011) Yes they can! *Autism* **15**, 421–435.

Nam, T.-J., Lee, J.-H., Park, S. And Suk, H.-J. (2014) Understanding the Relation between Emotion and Physical Movements. *International Journal of Affective Engineering* **13**, 217–226.

Neric, F.B., Beam, W.C., Brown, L.E. and Wiersma, L.D. (2009) Comparison of Swim Recovery and Muscle Stimulation on Lactate Removal After Sprint Swimming. *Journal of Strength and Conditioning Research* **23**, 2560–2567.

Oberer, N., Gashaj, V. and Roebers, C.M. (2017) Motor skills in kindergarten: Internal structure, cognitive correlates and relationships to background variables. *Human Movement Science* **52**, 170–180.

Ohara, R., Kanejima, Y., Kitamura, M. and Izawa, K.P. (2019) Association between Social Skills and Motor Skills in Individuals with Autism Spectrum Disorder: A Systematic Review. *European Journal of Investigation in Health, Psychology and Education* **10**, 276–296.

Okely, A.D., Booth, M.L. and Chey, T. (2004) Relationships between Body Composition and Fundamental Movement Skills among Children and Adolescents. *Research Quarterly for Exercise and Sport* **75**, 238–247.

Olivier, I., Palluel, E. and Nougier, V. (2008) Effects of attentional focus on postural sway in children and adults. *Experimental Brain Research* **185**, 341–345.

Oxendine, J.B. (1967) Generality and specificity in the learning of fine and gross motor skills. *Research Quarterly of the American Association for Health, Physical Education and Recreation* **38**.

Palmer, K.K., Matsuyama, A.L., Irwin, J.M., Porter, J.M. and Robinson, L.E. (2017) The effect of attentional focus cues on object control performance in elementary children. *Physical Education and Sport Pedagogy* **22**, 580–588.

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Sanchis-Moysi, J., Dorado, C., Mora-Custodio, R., et al. (2017) Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scandinavian Journal of Medicine & Science in Sports* **27**, 724–735.

Peinado, A.B., Benito, P.J., Barriopedro, M., Lorenzo, I., Maffulli, N. and Calderón, F.J. (2014) Heart rate recovery in elite Spanish male athletes. *Journal of Sports Medicine and Physical Fitness* **54**.

Pelland, J.C., Robinson, Z.P., Remmert, J.F., Cerminaro, R.M., Benitez, B., John, T.A., et al. (2022) Methods for Controlling and Reporting Resistance Training Proximity to Failure: Current Issues and Future Directions. *Sports Medicine* **52**, 1461–1472.

Pérez-Olea, J.I., Valenzuela, P.L., Aponte, C. and Izquierdo, M. (2018) Relationship Between Dryland Strength and Swimming Performance: Pull-Up Mechanics as a Predictor of Swimming Speed. *Journal of Strength and Conditioning Research* **32**, 1637–1642.

Pleša, J., Kozinc, Ž. and Šarabon, N. (2022) A Brief Review of Selected Biomechanical Variables for Sport Performance Monitoring and Training Optimization. *Applied Mechanics* **3**, 144–159.

Pollock, S., Gaoua, N., Johnston, M.J., Cooke, K., Girard, O. and Mileva, K.N. (2019) Training regimes and recovery monitoring practices of Elite British swimmers. *Journal of Sports Science and Medicine* **18**.

Popp, N.J., Yokoi, A., Gribble, P.L. and Diedrichsen, J. (2020) The effect of instruction on motor skill learning. *Journal of Neurophysiology* **124**, 1449–1457.

Poppendieck, W., Faude, O., Wegmann, M. and Meyer, T. (2013) Cooling and Performance Recovery of Trained Athletes: A Meta-Analytical Review. *International Journal of Sports Physiology and Performance* **8**, 227–242.

Pratama, A.B. and Yimlamai, T. (2020) Effects of Active and Passive Recovery on Muscle Oxygenation and Swimming Performance. *International Journal of Sports Physiology and Performance* **15**, 1289–1296.

Pyne, D.B. and Sharp, R.L. (2014) Physical and Energy Requirements of Competitive Swimming Events. *International Journal of Sport Nutrition and Exercise Metabolism* **24**, 351–359.

Quarta, E., Cohen, E.J., Bravi, R. and Minciacchi, D. (2020) Future Portrait of the Athletic Brain: Mechanistic Understanding of Human Sport Performance Via Animal Neurophysiology of Motor Behavior. *Frontiers in Systems Neuroscience* **14**.

Rascon, J., Trujillo, E., Morales-AcuÑa, F. and Gurovich, A.N. (2020) Differences between Males and Females in Determining Exercise Intensity. *International journal of exercise science* **13**.

Reaburn, P.R.J. and Mackinnon, L.T. (1990) Blood lactate responses in older swimmers during active and passive recovery following maximal sprint swimming. *European Journal of Applied Physiology and Occupational Physiology* **61**, 246–250.

Rey, E., Carballo-Fazanes, A., Varela-Casal, C. and Abelairas-Gómez, C. (2020) Reliability of the test of gross motor development: A systematic review. *PLOS ONE* **15**, e0236070.

Rhea, M.R. (2004) Determining the Magnitude of Treatment Effects in Strength Training Research Through the Use of the Effect Size. *The Journal of Strength and Conditioning Research* **18**, 918.

Riewald, S. (2015) *Science of Swimming Faster*. (eds S Riewald and S Rodeo). Human Kinetics.

Robinson, L.E. (2011) The relationship between perceived physical competence and fundamental motor skills in preschool children. *Child: Care, Health and Development* **37**.

Rodríguez-Rosell, D., Yáñez-García, J.M., Sánchez-Medina, L., Mora-Custodio, R. and González-Badillo, J.J. (2020) Relationship Between Velocity Loss and Repetitions in Reserve in the Bench Press and Back Squat Exercises. *Journal of Strength and Conditioning Research* **34**, 2537–2547.

Roebers, C.M. and Kauer, M. (2009) Motor and cognitive control in a normative sample of 7-year-olds. *Developmental Science* **12**.

Roren, A., Mazarguil, A., Vaquero-Ramos, D., Deloose, J.-B., Vidal, P.-P., Nguyen, C., et al. (2022) Assessing Smoothness of Arm Movements With Jerk: A Comparison of Laterality, Contraction Mode and Plane of Elevation. A Pilot Study. *Frontiers in Bioengineering and Biotechnology* **9**.

Rosenbloom, L. (1994) Motor Development in Early and Later Childhood: Longitudinal Approaches. *Archives of Disease in Childhood* **71**.

Sadowski, J., Mastalerz, A. and Gromisz, W. (2020) Transfer of Dry-Land Resistance Training Modalities to Swimming Performance. *Journal of Human Kinetics* **74**, 195–203.

Samozino, P., Rejc, E., Di Prampero, P.E., Belli, A. And Morin, J.-B. (2012) Optimal Force–Velocity Profile in Ballistic Movements—Altius. *Medicine & Science in Sports & Exercise* **44**, 313–322.

Sánchez-Medina, L., Pallarés, J., Pérez, C., Morán-Navarro, R. and González-Badillo, J. (2017) Estimation of Relative Load From Bar Velocity in the Full Back Squat Exercise. *Sports Medicine International Open* **01**, E80–E88.

Scheuer, C., Herrmann, C. and Bund, A. (2019) Motor tests for primary school aged children: A systematic review. *Journal of Sports Sciences* **37**, 1097–1112.

Schmidt, R., Lee, T., Winstein, C., Wulf, G. and Zelaznik, H. (2019) Motor Control and Learning: A Behavioral Emphasis, 6th Edition. *Medicine & Science in Sports & Exercise* **51**, 226–226.

Schubert, M., Clark, A. and De La Rosa, A. (2018) The Polar® OH1 Optical Heart Rate Sensor is Valid during Moderate-Vigorous Exercise. *Sports Medicine International Open* **02**, E67–E70.

Seashore, H.G. (1942) Some relationships of fine and gross motor abilities. *Research Quarterly of the American Association for Health, Physical Education and Recreation* **13**.

Sgrò, F., Mango, P., Pignato, S., Schembri, R., Licari, D. and Lipoma, M. (2017a) Assessing Standing Long Jump Developmental Levels Using an Inertial Measurement Unit. *Perceptual and Motor Skills* **124**, 21–38.

Sgrò, F., Quinto, A., Messana, L., Pignato, S. and Lipoma, M. (2017b) Assessment of gross motor developmental level in italian primary school children. *Journal of Physical Education and Sport* **17**, 1954–1959.

Shell, S.J., Slattery, K., Clark, B., Broatch, J.R., Halson, S., Kellmann, M., et al. (2020) Perceptions and use of recovery strategies: Do swimmers and coaches believe they are effective? *Journal of Sports Sciences* **38**, 2092–2099.

Slykerman, S., Ridgers, N.D., Stevenson, C. and Barnett, L.M. (2016) How important is young children's actual and perceived movement skill competence to their physical activity? *Journal of Science and Medicine in Sport* **19**.

Sorgente, V., Agudo-Ortega, A., Lopez-Hernandez, A., Santos del Cerro, J., Minciacchi, D. and González Ravé, J.M. (2023a) Relationship between Maximum Force–Velocity Exertion and Swimming Performances among Four Strokes over Medium and Short Distances: The Stronger on Dry Land, the Faster in Water? *Journal of Functional Morphology and Kinesiology* **8**, 20.

Sorgente, V., Cohen, E.J., Bravi, R. and Minciacchi, D. (2021) Crosstalk between Gross and Fine Motor Domains during Late Childhood: The Influence of Gross Motor Training on Fine Motor Performances in Primary School Children. *International Journal of Environmental Research and Public Health* **18**, 11387.

Sorgente, V., Cohen, E.J., Bravi, R. and Minciacchi, D. (2022) The Best of Two Different Visual Instructions in Improving Precision Ball-Throwing and Standing Long Jump Performances in Primary School Children. *Journal of Functional Morphology and Kinesiology* **7**, 8.

Sorgente, V., Lopez-Hernandez, A., Minciacchi, D. and González Ravé, J.M. (2023b) Diving into Recovery. The Effects of Different Post-Competition Protocols for Enhancing Physio-Psychological Parameters in National Level Youth Swimmers. *Journal of Sports Science and Medicine* **22**, 739–747.

Sorgente, V. and Minciacchi, D. (2023) Efficiency in Kinesiology: Innovative Approaches in Enhancing Motor Skills for Athletic Performance. *Journal of Functional Morphology and Kinesiology* **8**, 111.

Southard, D. (2011) Attentional Focus and Control Parameter. *Research Quarterly for Exercise and Sport* **82**, 652–666.

Souza, C.T., Santos, D.C.C., Tolocka, R.E., Baltieri, L., Gibim, N.C. and Habechian, F.A.P. (2010) Avaliação do desempenho motor global e em habilidades motoras axiais e apendiculares de lactentes frequentadores de creche. *Revista Brasileira de Fisioterapia* **14**.

De Stefani, E., Rodà, F., Volta, E., Pincolini, V., Farnese, A., Rossetti, S., et al. (2020) Learning new sport actions: Pilot study to investigate the imitative and the verbal instructive teaching methods in motor education. *PLOS ONE* **15**, e0237697.

Strong, W.B., Malina, R.M., Blimkie, C.J.R., Daniels, S.R., Dishman, R.K., Gutin, B., et al. (2005) Evidence based physical activity for school-age youth. *Journal of Pediatrics* **146**.

Suchomel, T.J., Nimphius, S., Bellon, C.R. and Stone, M.H. (2018) The Importance of Muscular Strength: Training Considerations. *Sports Medicine* **48**, 765–785.

Tanner, R.K., Fuller, K.L. and Ross, M.L.R. (2010) Evaluation of three portable blood lactate analysers: Lactate Pro, Lactate Scout and Lactate Plus. *European Journal of Applied Physiology* **109**, 551–559.

Temple, V.A., Crane, J.R., Brown, A., Williams, B.-L. and Bell, R.I. (2016) Recreational activities and motor skills of children in kindergarten. *Physical Education and Sport Pedagogy* **21**, 268–280.

Thompson, S.W., Rogerson, D., Ruddock, A. and Barnes, A. (2020) The Effectiveness of Two Methods of Prescribing Load on Maximal Strength Development: A Systematic Review. *Sports Medicine* **50**, 919–938.

Tortella, P., Haga, M., Loras, H., Sigmundsson, H. and Fumagalli, G. (2016) Motor Skill Development in Italian Pre-School Children Induced by Structured Activities in a Specific Playground. *PLOS ONE* **11**, e0160244.

Toubekis, A.G., Douda, H.T. and Tokmakidis, S.P. (2005) Influence of different rest intervals during active or passive recovery on repeated sprint swimming performance. *European Journal of Applied Physiology* **93**, 694–700.

Toubekis, A.G., Smilios, I., Bogdanis, G.C., Mavridis, G. and Tokmakidis, S.P. (2006) Effect of different intensities of active recovery on sprint swimming performance. *Applied Physiology, Nutrition, and Metabolism* **31**, 709–716.

Toubekis, A.G., Tsolaki, A., Smilios, I., Douda, H.T., Kourtesis, T. and Tokmakidis, S.P. (2008) Swimming Performance After Passive and Active Recovery of Various Durations. *International Journal of Sports Physiology and Performance* **3**, 375–386.

Ulrich, D. (2017a) The Test of Gross Motor Development-3 (TGMD-3): Administration, Scoring, & International Norms. *Hacettepe Journal of Sport Sciences*.

Ulrich, D.A. (2017b) Introduction to the Special Section: Evaluation of the Psychometric Properties of the TGMD-3. *Journal of Motor Learning and Development* **5**, 1–4.

Uygur, F. (2020) Past, present and future of kinesiology. In: *Comparative Kinesiology of the Human Body*. Elsevier. 3–12.

Valentini, N.C., Rudisill, M.E., Bandeira, P.F.R. and Hastie, P.A. (2018) The development of a short form of the Test of Gross Motor Development-2 in Brazilian children: Validity and reliability. *Child: Care, Health and Development* **44**, 759–765.

Veldman, S.L.C., Okely, A.D. and Jones, R.A. (2015) Promoting Gross Motor Skills in Toddlers: The Active Beginnings Pilot Cluster Randomized Trial. *Perceptual and Motor Skills* **121**, 857–872.

Vescovi, J.D., Falenchuk, O. and Wells, G.D. (2011) Blood Lactate Concentration and Clearance in Elite Swimmers During Competition. *International Journal of Sports Physiology and Performance* **6**, 106–117.

Wakayoshi, K., Yoshida, T., Udo, M., Kasai, T., Moritani, T., Mutoh, Y., et al. (1992) A Simple Method for Determining Critical Speed as Swimming Fatigue Threshold in Competitive Swimming. *International Journal of Sports Medicine* **13**, 367–371.

Wallace, L.K., Slattery, K.M. and Coutts, A.J. (2009) The Ecological Validity and Application of the Session-RPE Method for Quantifying Training Loads in Swimming. *Journal of Strength and Conditioning Research* **23**, 33–38.

Wang, C.-H., Chang, C.-C., Liang, Y.-M., Shih, C.-M., Chiu, W.-S., Tseng, P., et al. (2013) Open vs. Closed Skill Sports and the Modulation of Inhibitory Control. *PLoS ONE* **8**, e55773.

Webster, E.K., Martin, C.K. and Staiano, A.E. (2019) Fundamental motor skills, screen-time, and physical activity in preschoolers. *Journal of Sport and Health Science* **8**, 114–121.

Westendorp, M., Hartman, E., Houwen, S., Smith, J. and Visscher, C. (2011) The relationship between gross motor skills and academic achievement in children with learning disabilities. *Research in Developmental Disabilities* **32**.

Weyand, P.G., Sternlight, D.B., Bellizzi, M.J. and Wright, S. (2000) Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology* **89**, 1991–1999.

Wilcock, I.M., Cronin, J.B. and Hing, W.A. (2006) Physiological Response to Water Immersion. *Sports Medicine* **36**, 747–765.

Williams, A.M. and Ford, P.R. (2008) Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology* **1**, 4–18.

Williams, H.G., Pfeiffer, K.A., O'Neill, J.R., Dowda, M., McIver, K.L., Brown, W.H., et al. (2008) Motor Skill Performance and Physical Activity in Preschool Children. *Obesity* **16**, 1421–1426.

Włodarczyk, M., Adamus, P., Zieliński, J. and Kantanista, A. (2021) Effects of Velocity-Based Training on Strength and Power in Elite Athletes—A Systematic Review. *International Journal of Environmental Research and Public Health* **18**, 5257.

Wrotniak, B.H., Epstein, L.H., Dorn, J.M., Jones, K.E. and Kondilis, V.A. (2006) The relationship between motor proficiency and physical activity in children. *Pediatrics* **118**.

Wu, W.-L., Wu, J.-H., Lin, H.-T. and Wang, G.-J. (2003) Biomechanical analysis of the standing long jump. *Biomedical Engineering: Applications, Basis and Communications* **15**, 186–192.

Wulf, G., Chiviacowsky, S., Schiller, E. and Ávila, L.T.G. (2010a) Frequent External-Focus Feedback Enhances Motor Learning. *Frontiers in Psychology* **1**.

Wulf, G., McNevin, N.H., Fuchs, T., Ritter, F. and Toole, T. (2000) Attentional Focus in Complex Skill Learning. *Research Quarterly for Exercise and Sport* **71**, 229–239.

Wulf, G., Shea, C. and Lewthwaite, R. (2010b) Motor skill learning and performance: a review of influential factors. *Medical Education* **44**, 75–84.

Zeng, N., Ayyub, M., Sun, H., Wen, X., Xiang, P. and Gao, Z. (2017) Effects of Physical Activity on Motor Skills and Cognitive Development in Early Childhood: A Systematic Review. *BioMed Research International* **2017**, 1–13.

Zhang, X., Feng, S., Peng, R. and Li, H. (2022) The Role of Velocity-Based Training (VBT) in Enhancing Athletic Performance in Trained Individuals: A Meta-Analysis of Controlled Trials. *International Journal of Environmental Research and Public Health* **19**, 9252.

Zhao, J., Mao, J. and Tan, J. (2022) Global trends and hotspots in research on extended reality in sports: A bibliometric analysis from 2000 to 2021. *DIGITAL HEALTH* **8**, 205520762211311.