ANALYSIS OF HANDGRIP STRENGTH DISPARITIES AND MANUAL ASYMMETRY IN PRIMARY SCHOOL CHILDREN

Priscyla PRAXEDES*[1], Sara PEREIRA[1], José MAIA[1], Olga VASCONCELOS[1]

[1] University of Porto, Faculty of Sport, Porto, Portugal
*Corresponding author: priscylapraxedes@hotmail.com

https://doi.org/10.35189/dpeskj.2024.63.4.4

Abstract. *Hand asymmetry can be influenced by both biological and environmental factors, emerges early, and impacts motor skills and human development. Physical differences between boys and girls during childhood, such as body composition, may influence hand strength and asymmetry. Aims: This study examines handgrip strength and asymmetry in Portuguese children aged 6 to 10. Data from the RUSH project comprises 1504 children (760 girls) aged 6-10. Right-hand preference was observed in 90.9% of girls and 89.8% of boys. Manual grip was assessed using a handheld dynamometer (T.K.K. 5401). Descriptive statistics are presented as means and standard deviations. Within each sex, a one-way ANOVA was used to test for age-related differences, and the LSD test was used for post hoc multiple comparisons. All analyses were conducted using SPSS software version 29, with the significance level set at 5%. Older children were stronger in both hands (girls – preferred: $F=101.682$, $p<0.001$; non-preferred: $F=100.589$, $p<0.001$; boys – preferred: $F=69.419$, $p<0.001$; non-preferred: $F=67.867$, $p<0.001$). Significant differences in hand asymmetry were also observed between age groups in both girls ($F=4.892$, $p<0.05$) and boys ($F=7.764$, $p<0.05$). Specifically, it was found that girls aged 6 and 10 and boys aged 10 had higher asymmetry values than those aged 6, 7, 8, and 9. Hand strength and asymmetry appear to change with older children showing greater discrepancies between preferred and non-preferred hands. Further studies are required to understand the mechanisms behind these differences.*

Keywords*: manual laterality; hand grip strength; hand asymmetry; children.*

Received: *16 September 2024* / **Accepted:** *18 December 2024* / **Published:** *30 December 2024*

Introduction

The handgrip test is a key marker of maximum hand strength and is widely used due to its simplicity and low cost (Massy-Westropp et al., 2004). Hand function can be indirectly assessed through motor and sensory tests or directly by measuring handgrip strength (Cooper et al., 2011). There is evidence that children's handgrip strength is associated with various health outcomes (Bae et al., 2015; Pepplinkhuizen et al., 2023; Saraiva et al., 2021). For instance, Bae et al. (2015) revealed a strong correlation between lung capacity and hand strength, both in the right and left hand, indicating that children with better lung function generally show greater handgrip strength, regardless of handedness. Further, Saraiva et al. (2021), in a systematic review, demonstrated that upper limb muscular strength is linked to bone health in children and young adults.

Children's handgrip strength varies by sex and age (Omar et al., 2018). For example, Jürimäe et al. (2011) found that handgrip strength progressively increases with age, with boys outperforming girls, a find consistent with Malina et al. (2010). However, Montalcini et al. (2016) and Sartorio et al. (2002) found no statistically significant differences between sexes. Although there is evidence that cultural and environmental factors may contribute to these differences, the most relevant explanation is linked to biological factors, particularly physiological and maturational factors (Malina et al., 2004).

In addition to handgrip strength, manual asymmetry, as the consequence of the natural inclination of individuals to prefer one hand over the other when performing precise motor tasks, namely writing, drawing, or manipulating objects, is another critical marker of motor development and health (Carson et al., 1995). This asymmetry is generally associated with cerebral lateralization, wherein the dominant hemisphere for language (typically the left) also plays an essential role in controlling fine motor skills of the opposite hand (Fagard, 2013). For instance, in most right-handed individuals, the left hemisphere is dominant for both language and fine motor control of the right hand (MacNeilage et al., 2009). These results suggest that the left side of the brain may be naturally better at controlling the right hand, which could explain why most people are right-handed. However, other studies, such as that of Verstynen et al. (2005), indicate that the brain is sometimes more clear-cut. A brain imaging study found that simple hand movements require less activation in the same hemisphere that controls the hand, whereas more complex movements engage both hemispheres to a greater extent (Timofti, 2010). This suggests that the left and right hemispheres interact differently depending on the complexity of the motor task. Manual asymmetry thus provides valuable insights into how the human brain organizes motor functions and its intricate relationship with cerebral lateralization (Scharoun & Bryden, 2014).

Nicolay and Walker (2005) indicated that manual asymmetry is common in children, but high levels of asymmetry may be associated with motor imbalances or specific neurological conditions. These authors also reported that boys tend to exhibit more significant manual asymmetry than girls, possibly due to differences in physical activities and games involving fine and gross motor coordination. These sex differences in manual asymmetry may also reflect variations in cerebral laterality and neuromotor development, suggesting that boys are more likely to develop specific dominant motor skills (Díaz-Pereira et al., 2023). In addition to sex differences, manual asymmetry also varies with age (Faria et al., 2017; Ferreira et al., 2011; Gómez-Campos et al., 2022). For example, Houwen et al. (2010) observed that manual asymmetry tends to decrease with age, especially between the ages of 5 and 10, as children engage in a wider variety of motor activities requiring both hands. This decreased asymmetry with age suggests that bilateral motor development becomes more balanced over time as children grow and gain experience and improve motor control. Research on lateral asymmetry in children often encounters challenges that may compromise the quality and generalizability of results (Bondi et al., 2020; Díaz-Pereira et al., 2023; Omar et al., 2018). Small sample sizes, selection bias, and a lack of standardized assessment methods are some of the most common limitations in this research area. Additionally, inadequate control of confounding variables, subjective assessment methods, and the absence of longitudinal follow-up can hinder data interpretation.

Despite the growing research on handgrip strength and manual asymmetry, there are still gaps in our understanding of these variations. Hence, this study aims to analyze handgrip strength and manual asymmetry in relation to age in primary school children.

Methodology

Participants and Procedure

The data for this paper were obtained from the RUSH project (Maia et al., 2022), conducted in the municipality of Matosinhos in partnership with the city council. Matosinhos is a sub-region of the Porto Metropolitan area, located in the northern region of the country. The children were sampled from the 32 schools, and parents provided informed, free and explicit consent in accordance with the ethical principles outlined in the Declaration of Helsinki.

The study sample consists of 1504 children (760 girls) aged 6 to 10 years (Table 1). The children are distributed across the 1st, 2nd, 3rd, and 4th grades of the first cycle of basic education from 32 schools in Matosinhos.

Table 1: *Sample size distribution, by age and sex*

	6y	7y	8y	9y	10y	Total
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Girls	130 (17.1)	176 (23.2)	212 (27.9)	165 (21.7)	77 (10.1)	760 (50.53)
Boys	109 (14.7)	208 (28)	180 (24.2)	158 (21.2)	89 (12.0)	744 (49.47)
Total	239 (15.9)	384 (25.5)	392 (26.1)	323 (21.5)	166 (11.0)	1504 (100%)

Note. y=years.

The sample consisted of 760 girls (50.53%) and 744 boys (49.47%), ensuring a balanced analysis between sexes. The age distribution revealed that the highest proportion of children was in the 8-year-old age group (26.1%), followed by the 7-year-old group (25.5%), while the smallest participation was observed among 10-year-olds (11%).

Preferred hand

Each child's preferred hand was determined through individual assessments to ensure accuracy. During these assessments, children were asked a series of targeted questions about their daily activities, specifically: (i) Which hand do you use to write? (ii) Which hand do you use to eat soup? and (iii) Which hand do you use to brush your teeth? These questions were designed to capture the hand used for tasks requiring fine motor control and precision. Based on the children's answers, they were then categorized as either right-handed or left-handed. The responses were analyzed, and the results are presented in Table 2, showing the distribution of boys and girls according to their preferred hand. The data reveal that the majority of children, regardless of gender, prefer using their right hand for all tasks. This right-hand preference aligns with broader population trends, indicating a dominant pattern of right-handedness in the sample.

Table 2. *Preferred hand frequency among girls and boys*

	Girls (n= 760)	Boys (n= 744)
	%	%
Preferred Hand		
Right-hand	91.6	89.2
Left-hand	8.4	10.8

Handgrip test

The manual grip test (maximal static strength) from Eurofit (1993) was performed using a handheld dynamometer (TKK 5401, Japan). Children were instructed to stand upright with the arm extended while the grip dynamometer was adjusted to fit their hand size. They were then asked to squeeze the dynamometer with maximum force for 5 seconds. Two attempts were made by each child, and the final result was the mean of the two attempts expressed in kilograms-force (kg^f).

Manual laterality and asymmetry

The absolute values of lateral asymmetry were calculated by measuring the difference in performance between the preferred and non-preferred hand for specific motor tasks. This method involves subtracting the performance score of the non-preferred hand from that of the preferred hand. The resulting value indicates the degree of asymmetry between the two limbs.

A score closer to 0 signifies minimal asymmetry, meaning the child performs similarly with both hands, indicating more balanced bilateral coordination. In contrast, higher scores reflect greater differences in performance, suggesting a stronger dominance of one hand over the other. This approach to quantifying lateral asymmetry provides a clear, objective measure of how much better the preferred hand is in comparison to the non-preferred hand for tasks requiring fine motor control. The interpretation of these values aligns with the findings of Lage et al. (2008), where lower asymmetry is associated with improved ambidexterity or less pronounced hand dominance.

Statistical Analysis

Descriptive statistics are presented as means and standard deviations. Within each sex, a one-way ANOVA model was used to test for differences between age groups, and the Least Significant Difference test was applied for *post hoc* multiple comparisons. All analyses were conducted using SPSS software version 29, with the significance level set at 5%.

Results

Table 3 presents the results for hand grip strength in the preferred and non-preferred hands, as well as manual asymmetry, analyzed by sex and age. The F-values indicate results of the analysis of variance (ANOVA) across age groups, separated by sex, examining differences in strength between preferred and non-preferred hands, as well as manual asymmetry. These values indicate the magnitude of the differences between age groups, considering the variation within and between groups. The results demonstrated a progressive and significant increase in manual strength for both the preferred and non-preferred hands as age increased in both sexes. Among girls, preferred hand strength increased from 9.58±2.10 KgF at age 6 to 15.96±3.55 KgF at age 10 ($F=101.68$, $p<0.05$), while non-preferred hand strength increased from 9.13±2.23 KgF to 15.22±3.42 KgF in the same period ($F=100.59$, $p<0.05$). Post-hoc comparisons indicated that the strength of both the preferred and non-preferred hands was significantly lower at younger ages compared to older age groups, demonstrating a continuous progression throughout development. Manual asymmetry in girls also increased with age, from 4.15±3.50 at age 6 to 6.36±5.79 at age 10 ($F=4.98$, $p<0.05$), with significant differences observed only between ages 6 and 10.

A similar trend was observed in boys. Preferred hand strength increased from 10.18±2.62 KgF at age 6 to 15.82±3.79 KgF at age 10 ($F = 69.42$, $p < 0.05$), while non-preferred hand strength ranged from 10.01±2.67 KgF to 15.21±3.80 KgF in the same period ($F=67.87$, $p<0.05$). Post-hoc analyses confirmed significant increases between most age groups, demonstrating a continuous pattern of progression. Manual asymmetry in boys increased from 3.93±3.63 at age 6 to 7.08±5.88 at age 10 ($F=7.76$, $p<0.05$), with significantly higher values at age 10 compared to all other age groups.

Overall, the results indicate that manual strength, in both the preferred and non-preferred hands significantly increase throughout childhood in both sexes. Manual asymmetry also increases with age, especially among boys at age 10, suggesting a more pronounced development of manual specialization at this stage. These findings reinforce the link between motor development and the progressive increase in manual strength during childhood growth.

Table 3. Overview of results of the preferred hand, non-preferred hand, and manual asymmetry, stratified by sex and age *(*p<0.05)*

	Girls						
	6y	7y	8y	9y	10y		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F test	*Post-hoc* comparisons with statistical significance
Preferred hand (Kg^F)	9.58±2.10	10.95±2.58	12.25±2.68	14.87±3.55	15.96±3.55	101.68*	6<7;6<8;6<9;6<10 7<8;7<9;7<10 8<9;8<10
Non-preferred hand (Kg^F)	9.13±2.23	10.45±2.28	11.79±2.54	14.16±3.42	15.22±3.42	100.59*	6<7;6<8;6<9;6<10 7<8;7<9;7<10 8<9;8<10
Manual Asymmetry	4.15±3.50	4.16±4.05	4.74±4.25	5.51±5.00	6.36±5.79	4.98*	6<10
	Boys						
	6y	7y	8y	9y	10y		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F test	*Post-hoc* comparisons with statistical significance
Preferred hand (Kg^F)	10.18±2.62	11.63±3.21	12.88±2.74	15.03±3.05	15.82±3.79	69.42*	6<7;6<8;6<9;6<10 7<8;7<9;7<10 8<9;8<10
Non-preferred hand (Kg^F)	10.01±2.67	11.26±2.73	12.13±2.56	14.60±3.26	15.21±3.80	67.87*	6<7;6<8;6<9;6<10 7<8;7<9;7<10 8<9;8<10
Manual Asymmetry	3.93±3.63	4.35±3.77	5.07±4.57	4.97±4.34	7.08±5.88	7.76*	10>6;10>7;10>8;10>9

Discussion and Conclusions

This study analyzed grip strength and manual asymmetry in Portuguese boys and girls aged 6 to 10 years. The results indicate that both preferred and non-preferred hand strength increase with age, with older children outperforming their younger peers. Additionally, older boys and girls exhibit more significant lateral asymmetry compared to their younger same-sex peers.

Our research found that over 90.9% of girls and 89.8% of boys show a preference for the right hand, a preference that has also been noted in another study (Corballis, 2009; Hepper et al., 1991; Omar et al., 2018). A survey conducted by Corballis (2009) revealed that the preference for using the right side of the body instead of the left, particularly regarding the hands and feet, is observed in nearly 90% of the total population. This preference arises early in prenatal life and is independent of demographic characteristics such as gender and ethnicity (Fagard, 2013). In another study conducted on Arab children, it was found that right-hand dominance was reported in 475 children (90.5%), comprising 196 (37.3%) boys and 279 (53.2%) girls. In comparison, 50 children (9.5%) reported left-hand dominance, comprising 26 (4.9%) boys and 24 (4.6%) girls (Omar et al., 2018). The preference for using a specific side of the body is linked to hemispheric specialization of the brain, where the opposite hemisphere of the brain gains greater control over movements (MacNeilage et al., 2009). This specialization may provide advantages, allowing each cerebral hemisphere to develop specific skills more efficiently. The preferred hand performs better in particular tasks and also shows less variability when executing them (Bondi et al., 2020). The explanation for the superior performance of the preferred hand lies in its superior ability to modulate force with precision, thanks to the rapid circuits of contraction and relaxation of the wrist's antagonistic muscles (de Kovel et al., 2019). Therefore, the preferred hand presents a significant advantage due to its more efficient neuromuscular control, enabling a more consistent and precise execution of various tasks. This understanding highlights the importance of refined motor coordination development in improving performance in activities requiring complex hand movements.

Our results also show that older boys and girls exhibit greater handgrip strength in both hands, aligning with findings from other studies (Alqahtani et al., 2023; Omar et al., 2018). A study conducted with Iranian children aged 7 to 10 years found that younger boys and girls exhibited lower handgrip strength, regardless of their preferred hand (Alqahtani et al., 2023). Another study by Omar et al. (2018) provided normative data on handgrip strength among Saudi boys and girls aged 6 to 12 years, using age-based growth curves. These results confirm progressive and significant increases in handgrip strength as children age, with older children exhibiting greater strength in both sexes. The lower handgrip strength observed in younger children is a multifaceted phenomenon primarily attributed to the developmental stage of the neuromuscular system during the early years of life (Payne & Isaacs, 2020). During this crucial period, the muscles of the hands and fingers are still developing and have not yet reached full maturity in size and strength. Additionally, neuromuscular control required to coordinate fine hand movements is still developing, which may limit the ability to exert effective handgrip strength (Malina et al., 2004). Furthermore, the lack of experience and practice in activities requiring handgrip strength also plays a significant role, as younger children have fewer opportunities to develop and strengthen their hand muscles through daily activities.

However, as this study is observational, we cannot establish a causal relationship between age and strength, requiring longitudinal studies to analyze variations in strength at different sexes and ages over time (Teixeira, 2008). The increase in grip strength with age is due to muscular development and motor maturation, influenced by physiological growth and improved neuromuscular coordination. These findings highlight the importance of age-appropriate physical activities. The strength difference between preferred and non-preferred hands demonstrates how handedness affects motor development, suggesting that bilateral activities could help promote more balanced development (Hepping et al., 2015).

Our study also revealed that age influences asymmetry. The comparative values across different age groups, analyzed through post-hoc tests following the identification of significant differences, indicate a trend toward increased asymmetry with age. Bondi et al. (2020) reported similar findings, observing a preference-driven asymmetry in handgrip strength among boys and girls aged 7 to 12 years, reinforcing the idea that motor control refines over time.

This pattern can be attributed to the continuous development of motor skills as children grow and engage in activities requiring different levels of manual strength. The difference in asymmetry between age groups reflects various aspects of their development. In the motor domain, lateral preference, such as the preference for one hand or foot, becomes more pronounced as children grow, resulting in more asymmetrical differences in motor skills performance (Scharoun & Bryden, 2014). This may be partly explained by uneven physical growth of different body parts, which can create temporary asymmetries that become more evident in older children. Additionally, cognitively, the specialization of cerebral hemispheres intensifies with age, leading to more asymmetric brain activation during specific tasks (Díaz-Pereira et al., 2023). Another contributing factor is the social context, since varied experiences and exposures lead to more marked preferences and skills, contributing to more significant asymmetry in the capabilities and interests of older children. These changes reflect the complex interaction between biological maturation and environmental influences throughout childhood development (Díaz-Pereira et al., 2023).

Lateral asymmetry significantly plays an important role in motor development during childhood. Children with pronounced asymmetry often struggle with tasks requiring bilateral coordination, especially activities that demand both hands. Furthermore, when motor skills are concentrated in the dominant hand, while the non-dominant hand remains underused, it can affect activities requiring balanced use of both sides of the body.

This pattern appears in sports like basketball (Stöckel & Vater, 2014), where lateral preference influences athletic success. A study on basketball players found that sports training enhances motor function by improving the ability to use both hands, regardless of natural hand dominance (Gualdi-Russo et al., 2019). This suggests intensive sports training enhances hand-use flexibility. The study revealed two key correlations: first, individuals who exhibited stronger right-hand dominance in daily life also tended to favor their right hand in sports; second, increased training hours led to greater use of the non-dominant hand or both hands in sports-related tasks.

Moreover, the authors observed that lateral preference in daily activities was similar between athletes and the control group, indicating that basketball practice does not change players' natural hand preference in daily activities. However, athletes showed a higher frequency of using the left hand or both hands in specific basketball tasks, even when they were

right-handed in daily activities. This suggests intensive sports training enhances hand-use flexibility. Additionally, right-handed individuals tend to maintain their dominant hand preference in sports, though increased training leads to better non-dominant hand usage. While intensive training may reduce dominant hand reliance, these adult-focused findings in previous studies may not fully apply to children (Stöckel & Vater, 2014).

Future research should explore movement patterns and functional asymmetries across different ages and motor tasks to better understand how lateralization develops and impacts motor performance. Lateral performance asymmetry is crucial in sports requiring unilateral limb use, like basketball and handball, where athletes must effectively use both sides of their bodies. The dynamic nature of these sports requires quick adaptation and versatility with contralateral limbs. Furthermore, while greater manual asymmetry in older children indicates advanced motor skills in the preferred hand - beneficial for precise tasks like writing - it may also limit performance in activities requiring coordinated use of both hands, such as playing musical instruments or sports. Excessive hand skill disparity can reduce overall movement efficiency (Marinsek, 2016). Research on motor interventions suggests that bilateral training exercises that promote the balanced use of both hands can enhance coordination and reduce performance disparities, particularly in sports and music (Bobbio et al., 2009; Faria et al., 2017). Moreover, since children often rely heavily on their dominant hand, even when using both hands would be more efficient, encouraging diverse motor activities could help develop greater adaptability and improve task performance capabilities (Faria et al., 2017).

Our study found that hand strength varies with age in both sexes, with older children displaying more significant discrepancies between the preferred and non-preferred hands. While no significant differences in asymmetry were observed between sexes, older children exhibited more pronounced manual asymmetry compared to younger ones. However, to better understand these changes and their impact on child development, longitudinal studies are particularly relevant, as asymmetry can emerge in early childhood, diminish over time, or reappear in later childhood stages (Abe et al., 2022; Fraser et al., 2023; Katzmarzyk et al., 1997; Malina et al., 2010). Beyond physical and sports activities, the school environment plays a crucial role, as activities requiring manual skills influence both hand preference and performance. Key factors include neuromotor development, nutritional status, and the frequency of daily manual tasks, like writing and tool use. Cultural and family influences – particularly expectations about dominant hand use – interact with genetic factors to shape manual asymmetry patterns. Given these complex dynamics, we propose a longitudinal approach as essential for understanding the determinants and implications of manual asymmetry in children's overall development.

Our findings offer key practical insights for educators and health professionals. Age-specific exercise programs play a vital role in developing fine motor skills. For young children, activities should focus on using both hands together. For older children, the focus should shift to reducing hand asymmetry to improve overall coordination. The study shows that bilateral activities not only help balance hand strength but also boost motor flexibility and daily task performance. This research deepens our understanding of how neuromuscular maturation affects motor development. It also provides a foundation for creating interventions that enhance children's motor abilities and overall health – with important applications for both teaching and rehabilitation.

This research makes a significant contribution to understanding motor development in children, particularly regarding grip strength and manual asymmetry. The diverse sample of Portuguese boys and girls enables a comprehensive analysis of strength variations between sexes and the studied age range. Furthermore, the methodology employed, which combines objective strength measurements with a careful analysis of asymmetry, provides robust data that supports the conclusions of the study. By addressing the relationship between neuromuscular development and motor activity, the research underscores the importance of promoting opportunities for motor development in children, offering valuable insights for educators and health professionals.

Acknowledgment

We would like to acknowledge the following people who helped us in the tremendous task of implementing the RUSH project. First, we extend our appreciation to the city hall Mayor, Dra. Luísa Salgueiro, and the city-Councilors Prof. António Correia Pinto and Dr. Nuno Matos. A particular acknowledgement goes to Prof. Henrique Calisto, whose vision instilled in us the idea of this study. Second, we thank the City Hall Education officers, Drs. Lília Pinto and Hugo Cruz for their support. Third, we acknowledge the Physical Education coordinating team: João Begonha, Ana Cunha, and Ricardo Ferreira, for the dedication. Fourth, we express our gratitude to the Physical Education teachers for their active participation, Ana Cunha, Ana Sousa, Ana Melo, Ana Santos, Ana Almeida, André Azevedo, Carlos Nogueira, Cátia Rodrigues, Filipe Silva, Frederico Meneses, Hélia Cardoso, Joana Brito, João Begonha, João Costa, Luís Machado, Nuno Pereira, Patrícia Rocha, Ricardo Ferreira, Ricardo Jesus, Ricardo Oliveira, Rui Correia, Rui Costa, Pedro Madureira, Solange Pereira, Tanya Poças, Tiffany Poças, Telmo Ribeiro e Rute Poças. Fifth, we appreciate the contributions of the assessment team, Renata Lucena, Ricardo Santos, Priscyla Praxedes, Catarina Ferreira, Patrícia Soares, and José Guerra. Sixth, we extend our thanks to the twenty-five school coordinators for their contribution in this project. Finally, and most importantly, we give our most outstanding recognition to all the participating children and their families for their willingness to be part of the study.

Funding: This research did not receive any external funding.

Informed Consent Statement: Written informed consent was obtained for all participants involved in this study.

Data Availability Statement: Data can be made available upon request to the contact author.

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

References

Abe, T., Ozaki, H., Loenneke, J. P., Natsume, T., Deng, P., & Naito, H. (2022). A longitudinal study of handgrip strength asymmetry. *American Journal of Human Biology, 34*(6), e23722. https://doi.org/10.1002/ajhb.23722

Alqahtani, B. A., Alenazi, A. M., Elnaggar, R. K., Alshehri, M. M., Alhowimel, A., Najmi, A. A., Alasraj, M., & Alghadeir, M. (2023). Normative values for hand grip and pinch strength for 6 to 18 year-olds in Saudi Arabia. *BMC Musculoskelet Disord, 24*(1), 96. https://doi.org/10.1186/s12891-023-06197-0

Bae, J. Y., Jang, K. S., Kang, S., Han, D. H., Yang, W., & Shin, K. O. (2015). Correlation between basic physical fitness and pulmonary function in Korean children and adolescents: a cross-sectional survey. *The Journal of Physical Therapy Science, 27*(9), 2687-2692. https://doi.org/10.1589/jpts.27.2687

Bobbio, T., Gabbard, C., & Caçola, P. (2009). Interlimb coordination: an important facet of gross-motor ability. *Early Childhood Research & Practice, 11*(2), n2.

Bondi, D., Prete, G., Malatesta, G., & Robazza, C. (2020). Laterality in Children: Evidence for Task-Dependent Lateralization of Motor Functions. *International Journal of Environmental Research and Public Health, 17*(18). https://doi.org/10.3390/ijerph17186705

Carson, R. G., Chua, R., Goodman, D., Byblow, W. D., & Elliott, D. (1995). The preparation of aiming movements. *Brain and Cognition, 28*(2), 133–154.

Cooper, R., Kuh, D., Cooper, C., Gale, C. R., Lawlor, D. A., Matthews, F., & Hardy, R. (2011). Objective measures of physical capability and subsequent health: a systematic review. *Age Ageing, 40*(1), 14-23. https://doi.org/10.1093/ageing/afq117

Corballis, M. C. (2009). The evolution and genetics of cerebral asymmetry. *Philosophical Transactions of the Royal Society of London, Series B, Biological sciences, 364*(1519), 867-879. https://doi.org/10.1098/rstb.2008.0232

de Kovel, C. G. F., Carrión-Castillo, A., & Francks, C. (2019). A large-scale population study of early life factors influencing left-handedness. *Scientific Reports, 9*(1), 584. https://doi.org/10.1038/s41598-018-37423-8

Díaz-Pereira, M. P., López-Araujo, Y., & Lorenzo-Martínez, M. (2023). Examining Variations Between Everyday Life Handedness and Lateral Preferences for Sport-Specific Skills in Children. *Research Quarterly For Exercise and Sport, 94*(2), 368-373. https://doi.org/10.1080/02701367.2021.1994121

Europe, C. o. (1993). *Eurofit Tests of Physical Fitness, 2nd Edition.* (C. f. t. D. o. Sport, Ed.).

Fagard, J. (2013). The nature and nurture of human infant hand preference. *Annals of the New York Academy of Sciences, 1288*(1), 114-123. https://doi.org/10.1111/nyas.12051

Faria, I., Diniz, A., & Barreiros, J. (2017). Manual asymmetries in bimanual isochronous tapping tasks in children. *Acta Psychol (Amst), 172*, 41-48. https://doi.org/10.1016/j.actpsy.2016.11.005

Ferreira, A., Shimano, A., Mazer, N., Barbieri, C., Elui, V., & Fonseca, M. (2011). Grip and pinch strength in healthy children and adolescents. *Acta Ortopédica Brasileira, 19*, 92-97. https://doi.org/10.1590/S1413-78522011000200006

Fraser, B. J., Blizzard, L., Tomkinson, G. R., McGrath, R., Dwyer, T., Venn, A. J., & Magnussen, C. G. (2023). Tracking handgrip strength asymmetry from childhood to mid-life. *Acta Paediatr, 112*(11), 2408-2417. https://doi.org/10.1111/apa.16930

Gómez-Campos, R., Vidal Espinoza, R., de Arruda, M., Ronque, E. R. V., Urra-Albornoz, C., Minango, J. C., Alvear-Vasquez, F., de la Torre Choque, C., Castelli Correia de Campos, L. F., Sulla Torres, J., & Cossio-Bolaños, M. (2022). Relationship between age and handgrip strength: Proposal of reference values from infancy to senescence. *Front Public Health, 10*, 1072684. https://doi.org/10.3389/fpubh.2022.1072684

Gualdi-Russo, E., Rinaldo, N., Pasini, A., & Zaccagni, L. (2019). Hand Preference and Performance in Basketball Tasks. *International Journal of Environmental Research and Public Health*, *16*(22): 4336. https://doi.org/10.3390/ijerph16224336

Hepper, P. G., Shahidullah, S., & White, R. (1991). Handedness in the human fetus. *Neuropsychologia*, *29*(11), 1107-1111. https://doi.org/10.1016/0028-3932(91)90080-r

Hepping, A. M., Ploegmakers, J. J., Geertzen, J. H., Bulstra, S. K., & Stevens, M. (2015). The Influence of Hand Preference on Grip Strength in Children and Adolescents; A Cross-Sectional Study of 2284 Children and Adolescents. *PLoS One*, *10*(11), e0143476. https://doi.org/10.1371/journal.pone.0143476

Houwen, S., Hartman, E., & Visscher, C. (2010). The relationship among motor proficiency, physical fitness, and body composition in children with and without visual impairments. *Research in Developmental Disabilities*, 31(4), 862–870.

Jürimäe, T., Hurbo, T., & Jürimäe, J. (2009). Relationship of handgrip strength with anthropometric and body composition variables in prepubertal children. *Homo: internationale Zeitschrift fur die vergleichende Forschung am Menschen*, *60*(3), 225–238. https://doi.org/10.1016/j.jchb.2008.05.004

Katzmarzyk, P. T., Malina, R. M., & Beunen, G. P. (1997). The contribution of biological maturation to the strength and motor fitness of children. *Annals of Human Biology*, *24*(6), 493-505. https://doi.org/10.1080/03014469700005262

Lage, G. M., Gallo, L. G., de Miranda, M. G., Vieira, D. R., Schickler, D. J., Coelho, R. R., Ugrinowitsch, H., & Benda, R. N. (2008). Assimetrias manuais em tarefas de apontamento com diferentes níveis de complexidade. *Revista Portuguesa de Ciências do Desporto*, 8(1), 47–57.

MacNeilage, P. F., Rogers, L. J., & Vallortigara, G. (2009). Origins of the left & right brain. *Scientific American*, *301*(1), 60-67. https://doi.org/10.1038/scientificamerican0709-60

Maia, J., Pereira, S., Guimarães, E., Santos, C., Garganta, R., Vasconcelos, O., Farias, C., Garbeloto, F., Tani, G. & Katzmarzyk, P. (2022). *Rush: Return-to-school after COVID-19.* News - Universidade do Porto. https://rush.fade.up.pt/news/

Malina, R., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity*. Human Kinetics.

Malina, R. M., Reyes, M. E., Tan, S. K., & Little, B. B. (2010). Secular change in muscular strength of indigenous rural youth 6-17 years in Oaxaca, southern Mexico: 1968-2000. *Annals of Human Biology*, *37*(2), 168-184. https://doi.org/10.3109/03014460903325193

Marinsek, M. (2016). Lateral asymmetry as a function of motor practice type of complex upper- and lower-limb movement in young children. *Laterality*, *21*(3), 267-281. https://doi.org/10.1080/1357650x.2015.1127253

Massy-Westropp, N., Rankin, W., Ahern, M., Krishnan, J., & Hearn, T. C. (2004). Measuring grip strength in normal adults: reference ranges and a comparison of electronic and hydraulic instruments. *The Journal of Hand Surgery*, *29*(3), 514-519.

Montalcini, T., Ferro, Y., Salvati, M. A., Romeo, S., Miniero, R., & Pujia, A. (2016). Gender difference in handgrip strength of Italian children aged 9 to 10 years. *Italian Journal of Pediatrics*, *42:* 16. https://doi.org/10.1186/s13052-016-0226-y

Nicolay, C. W., & Walker, A. L. (2005). Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender. *International Journal of Industrial Ergonomics*, *35*(7), 605-618. https://doi.org/https://doi.org/10.1016/j.ergon.2005.01.007

Omar, M. T. A., Alghadir, A. H., Zafar, H., & Al Baker, S. (2018). Hand grip strength and dexterity function in children aged 6-12 years: A cross-sectional study. *Journal of Hand Therapy*, *31*(1), 93-101. https://doi.org/10.1016/j.jht.2017.02.004

Payne, V. G., & Isaacs, L. D. (2020). *Human Motor Development: A Lifespan Approach*. Routledge.

Pepplinkhuizen, S., Eshuis, G., Zijlstra, W. M. H., Timmer, C. Y., Ploegstra, M. J., Lelieveld, O., Hepping, A. M., Beenakker, E. A. C., & Berger, R. M. F. (2023). Muscle strength is reduced in children with pulmonary arterial hypertension. *Pulmonary Circulation, 13*(2), e12246. https://doi.org/10.1002/pul2.12246

Saraiva, B. T. C., Agostinete, R. R., Freitas Júnior, I. F., de Sousa, D. E. R., Gobbo, L. A., Tebar, W. R., & Christofaro, D. G. D. (2021). Association between handgrip strength and bone mineral density of Brazilian children and adolescents stratified by sex: a cross-sectional study. *BMC Pediatrics, 21*(1): 207. https://doi.org/10.1186/s12887-021-02669-1

Sartorio, A., Lafortuna, C. L., Pogliaghi, S., & Trecate, L. (2002). The impact of gender, body dimension and body composition on hand-grip strength in healthy children. *Journal of Endocrinological Investigation, 25*(5), 431-435. https://doi.org/10.1007/bf03344033

Scharoun, S. M., & Bryden, P. J. (2014). Hand preference, performance abilities, and hand selection in children. *Frontiers in Psychology*, *5*: 82. https://doi.org/10.3389/fpsyg.2014.00082

Stöckel, T., & Vater, C. (2014). Hand preference patterns in expert basketball players: interrelations between basketball-specific and everyday life behavior. *Human Movement Science, 38*, 143-151. https://doi.org/10.1016/j.humov.2014.09.002

Teixeira, L. A. (2008). Categories of manual asymmetry and their variation with advancing age. *Cortex, 44*(6), 707-716. https://doi.org/10.1016/j.cortex.2006.10.002

Timofti, I. C. (2010). The Complex Functioning of the Human Brain: The Two Hemispheres. *Brain. Broad Research in Artificial Intelligence and Neuroscience, 1*(2), 177-179.

Verstynen, T., Diedrichsen, J., Albert, N., Aparicio, P., & Ivry, R. B. (2005). Ipsilateral motor cortex activity during unimanual hand movements relates to task complexity. *Journal of Neurophysiology, 93*(3), 1209-1222. https://doi.org/10.1152/jn.00720.2004