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Motor coordination of eye-foot and ear-foot in adolescents: a comparison between adolescents engaged in rhythmic sports and ball sports

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ABSTRACT
Purpose. Motor coordination is essential for physical fitness and effective participation in sports. Various sports emphasise different types of coordination, with rhythmic sports focusing on timing and synchronisation and ball sports on quick reactions and precision. This study examines the impact of participation in rhythmic and ball sports on eye-foot and ear-foot coordination in adolescents.
Methods. Sixty adolescents (30 boys, 30 girls; mean age 12.95 ± 0.12 years) were divided into three groups: rhythmic sports, ball sports, and inactive, with 20 participants in each group. Eye-foot coordination was measured using a reaction time test, and ear-foot coordination was assessed by the coefficient of variation (CV) of inter-tap intervals (ITI). Data were analysed using one-way ANOVAs and post-hoc Bonferroni tests to compare the coordination skills among the three groups.
Results. The ball sports group demonstrated significantly better eye-foot coordination compared to both the rhythmic sports (p = 0.028) and inactive groups (p < 0.001). Additionally, the rhythmic sports group outperformed the inactive group in eye-foot coordination (p = 0.021). For ear-foot coordination, the rhythmic sports group showed greater timing consistency (lower CV_{ITI}) than both the ball sports (p = 0.012) and inactive groups (p = 0.034). These findings indicate the specific benefits of different types of sports training on motor coordination in adolescents.
Conclusions. Adolescents in ball sports show better eye-foot coordination, while those in rhythmic sports excel in ear-foot coordination. Sport-specific training significantly enhances these motor skills, indicating the need for tailored training programs to optimise adolescent development.
Key words: motor coordination, eye-foot coordination, ear-foot coordination, rhythmic sport, ball sport

Introduction

Motor coordination is a fundamental aspect of physical development in adolescents, significantly influencing both athletic performance and everyday motor tasks. This complex interaction between sensory inputs– such as visual and auditory stimuli–and motor outputs, especially those involving the lower limbs, are crucial for various physical activities [1, 2]. Within this domain, eye-foot and ear-foot coordination are particularly crucial, with significant implications for performance across different sports [3]. Eye-foot coordination refers to the synchronisation of visual information with foot movements, a skill predominantly used in ball sports like soccer and basketball, where precise timing and spatial awareness are crucial [4]. In contrast, ear-foot coordination involves integrating auditory cues with foot movements, which is essential in rhythmic sports like gymnastics and artistic swimming, where synchronisation with music is key [5, 6].

To assess these coordination skills, various methods have been employed in research. Eye-foot coordination is often measured using reaction time tests, where participants respond to visual stimuli by moving their feet to a target as quickly as possible [7, 8]. In contrast, ear-foot coordination is frequently evaluated using the coefficient of variation of inter-tap intervals (CV_{ITI}), which captures the precision of rhythmic motor synchronisation in response to auditory stimuli [9, 10]. These tests provide clear, quantifiable

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measures of the distinct coordination skills necessary for ball and rhythmic sports, making them appropriate for this study.

Despite the importance of these coordination skills, research comparing eye-foot and ear-foot coordination across different sports remains limited. Prior studies have primarily focused on general motor proficiency and the impact of specific training regimens [1, 2]. For instance, while some studies have examined motor coordination as a predictor of physical activity or fitness [11], few have explored the specific effects of different sports on eye-foot and ear-foot coordination among adolescents.

Additionally, recent studies have highlighted the concept of cross-modal transfer, where training in one sensory modality enhances performance in another. For example, rhythmic sports, which emphasise auditory-motor synchronisation, may also improve visual-motor coordination, suggesting broader benefits of diverse training stimuli [12, 13]. This notion raises the question of whether adolescents who participate in rhythmic sports may develop skills that transfer to ball sports, or vice versa, creating the potential for training programs to optimise coordination skills across multiple domains.

This study aims to address this gap by comparing eye-foot and ear-foot coordination in adolescents participating in rhythmic and ball sports. We hypothesise that ball sports will enhance eye-foot coordination, while rhythmic sports will promote superior ear-foot coordination [11, 14]. By investigating these differences, the study seeks to contribute to a broader understanding of motor coordination development in adolescents and provide practical recommendations for coaches and educators to optimise training methodologies.

Material and methods

Participants

The sample consisted of 60 adolescents (boys = 30, girls = 30), with a mean age of 12.95 years (*SD* ± 0.12). Participants were divided into three groups: rhythmic sports (*n* = 20), ball sports (*n* = 20), and inactive adolescents (*n* = 20) who did not regularly engage in organised physical activity, apart from compulsory physical education classes (boys = 10, girls = 10, mean age = 12.75 ± 0.85 years). The rhythmic sports group was comprised of girls participating in artistic swimming and rhythmic gymnastics (mean age = 13.30 ± 0.92 years), while the ball sports group comprised boys engaged in soccer and basketball (mean age 12.80 ± 0.70).

Participants in the sports groups trained at least three times per week for a minimum of two years, ensuring consistent engagement in their respective activities. These proportions were selected to balance the representation of sports, emphasising auditory-motor synchronisation (rhythmic sports) and visual-motor integration (ball sports). Exclusion criteria included any history of neuromotor disorders, recent injuries affecting performance, or prior experience in multiple sports, to ensure specialised training within each group.

An a priori power analysis using G*Power (version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf) with an effect size of 0.4, a significance level (α) of 0.05, and statistical power (1-β) of 0.7 indicated that 18 participants per group would be required to detect a moderate to large effect size. The final sample size of 20 participants per group exceeded this requirement, ensuring adequate statistical power.

Procedures

Eye-foot coordination test

The eye-foot coordination test utilised the FitLight Training system (FitLight Corp, Ontario, Canada), which consists of wireless LED lights that can be programmed to illuminate in specific sequences. Participants stood in the designated start position in a ready posture, focusing their gaze on eight FitLight devices. When a light illuminated on any device, participants moved as quickly as possible to touch the lit device with their foot, thereby extinguishing the light. They then returned to the starting position before responding to the next illuminated device. The intervals between light signals were randomised, ranging from 500 to 2500 ms. The primary measure for this test was reaction time (measured in milliseconds). Reaction time tests for visual-motor responses have demonstrated high test-retest reliability, with intraclass correlation coefficients (ICCs) ranging from 0.82 to 0.85 in similar contexts [15, 16]. These tests are considered reliable for assessing visual-motor integration, particularly in sports like soccer and basketball, where quick reactions are essential for performance.

Ear-foot coordination test

The ear-foot coordination test involved participants tapping their feet in synchronisation with metronome beats set at 750-millisecond intervals. Participants were instructed to initiate their first tap on the fifth beat and to continue tapping for 20 s (20,000 ms). They were required to maintain continuous tapping until the end of the test. Tapping was performed on a percussion pad (SPD ONE Percussion, Roland Corporation, Shizuoka, Japan), with participants isolated from audio feedback, hearing only the sound of their foot hitting the pad.

The test was recorded using Logic Pro X (Apple Inc., Cupertino, California, USA) at a sampling frequency of 44,100 Hz and then converted to digital audio files (.wav format) with the same sampling frequency. MATLAB (R2023b, MathWorks, Inc., Natick, Massachusetts, USA) was employed for signal analysis. The audio data underwent smoothing via a bidirectional second-order low-pass filter with a cut-off frequency of 150 Hz. After filtering, the onset of tappings was detected. For each participant, 24 response cycles were analysed. The inter-tap interval (ITI) was computed to provide an absolute measurement of timing. Additionally, the CV_{ITI} was calculated as the ratio of the standard deviation to the mean of ITIs, serving as an index of timing consistency. The ear-foot coordination test, measured using CV_{ITI}, has been shown to have high test-retest reliability, with ICCs exceeding 0.8 in studies focused on rhythmic timing [10, 17]. This test is valid for assessing motor synchronisation, particularly in rhythmic sports like artistic swimming and rhythmic gymnastics, where athletes rely heavily on precise timing to match auditory cues [18].

CV_{ITI} was chosen as the primary metric for ear-foot coordination because it effectively captures the participant's ability to maintain rhythmic consistency, a crucial skill in rhythmic sports. In activities such as artistic swimming and rhythmic gymnastics, athletes must synchronise their movements precisely with music or other auditory cues. CV_{ITI} quantifies the variability in ITIs, providing insight into how well participants can synchronise their foot movements with external rhythms. Given the importance of timing consistency in rhythmic sports, CV_{ITI} serves as a highly relevant and robust measure for evaluating motor coordination in this context.

Statistical analysis

Data collected from the coordination tests were analysed using SPSS (Version 29.0). Descriptive statistics, including means and standard deviations, were calculated for all variables. Two separate one-way ANOVAs were conducted to determine the main effects of the groups (rhythmic sports, ball sports, inactive) for each test type (eye-foot coordination and ear-foot coordination). The Greenhouse-Geisser correction was applied in cases where Mauchly's test of sphericity was significant. Post hoc tests with Bonferroni corrections were performed to identify specific group differences. Statistical significance was set at a p-value < 0.05.

Results

The means and standard deviations for the eye-foot and ear-foot coordination tests across the three groups (rhythmic sports, ball sports, and inactive) are presented in Table 1. Additionally, the results of the ANOVA for differences in eye-foot and ear-foot coordination tests between adolescents engaged in rhythmic sports, ball sports, and inactive adolescents are shown.

Eye-foot coordination test

Levene's test for homogeneity of variances indicated that the variances between groups were not significantly different for the eye-foot coordination test ($F(2,57)$ = 1.303, p = 0.28). A one-way ANOVA revealed a significant effect of the groups on eye-foot coordination, $F(2,57)$ = 15.099, p < 0.001, indicating significant differences in mean reaction times among the three groups.

To better understand the practical significance of these differences, effect sizes (Cohen's d) were calculated. The effect size between the ball sports and rhythmic sports groups was large (d = 2.02), while the effect size between the ball sports and inactive groups was moderate (d = 1.47). These findings suggest that athletes in ball sports, who demonstrated faster reaction times, may have a significant performance advantage in sports requiring quick visual-motor responses, such as soccer or basketball.

Table 1. Results of eye-foot and ear-foot coordination tests in rhythmic sports, ball sports, and inactive adolescents

	Rhythmic sports	Ball sports	Inactive	p
Eye-foot (reaction time, ms)	21.97 ± 2.09	18.44 ± 1.29^{a}	22.21 ± 3.08^{ab}	< 0.001
Ear-foot (CV_{ITI})	3.70 ± 1.03	5.64 ± 0.64^{a}	5.39 ± 3.30^{a}	0.007

[a] different from the rhythmic sports group, [b] different from the ball sports group
p < 0.05

Post hoc comparisons using the Bonferroni correction indicated that the ball sports group had significantly lower mean reaction times compared to both the rhythmic sports group ($p = 0.028$) and the inactive group ($p < 0.001$). Additionally, the rhythmic sports group had significantly lower mean reaction times compared to the inactive group ($p = 0.021$). Figure 1 illustrates these differences.

Ear-foot coordination test

Lavene's test for homogeneity of variances indicated that the variances between groups were significantly different for the ear-foot coordination test ($F(2,57) = 4.369$, $p = 0.017$). A one-way ANOVA revealed a significant effect of the groups on ear-foot coordination, $F(2,57) = 5.350$, $p = 0.007$, indicating significant differences in CV_{ITI} among the three groups.

Effect sizes (Cohen's d) were calculated to quantify the differences in CV_{ITI} across the groups. The effect size between the rhythmic sports and ball sports groups was moderate ($d = 1.24$), and the effect size between the rhythmic sports and inactive groups was moderate ($d = 0.72$). These results suggest that rhythmic sports athletes, whose training emphasises timing consistency, exhibited superior motor synchronisation compared to both ball sports athletes and inactive individuals.

Post hoc comparisons using the Bonferroni correction indicated that the rhythmic sports group had significantly lower CV_{ITI} compared to the ball sports group ($p = 0.012$) and the inactive group ($p = 0.034$). No sig-

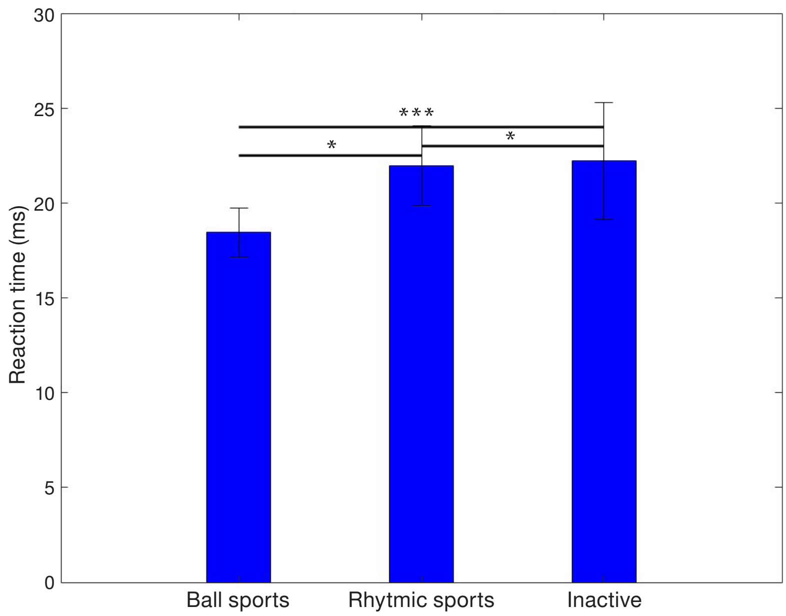

Figure 1. Eye-foot coordination (reaction time) by group. Significant differences are indicated: *** $p < 0.001$, * $p < 0.05$

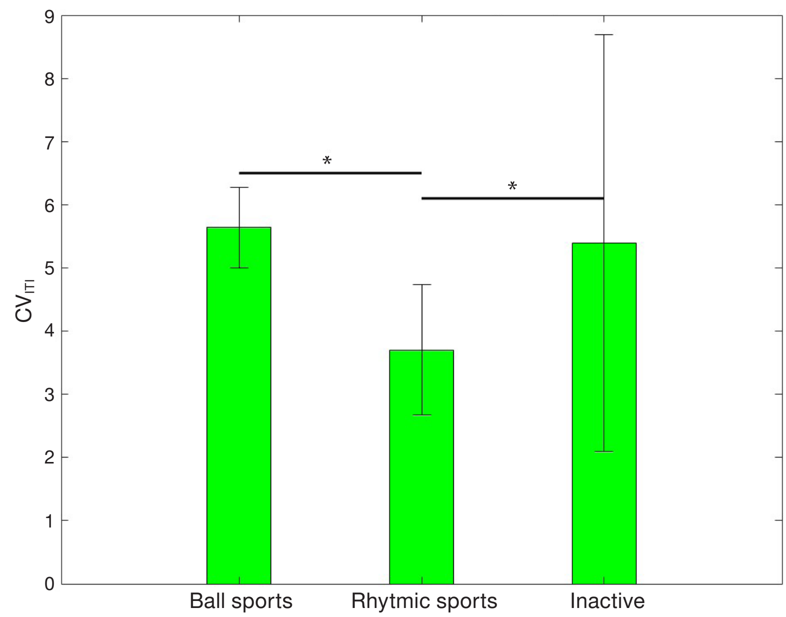

Figure 2. Ear-foot coordination (CV_{ITI}) by group. Significant differences are indicated: * $p < 0.05$

nificant difference was found between the ball sports and inactive groups (p = 1.000). Figure 2 shows these differences.

Discussion

This study aimed to investigate and compare the motor coordination skills of adolescents engaged in rhythmic sports, ball sports, and those not regularly participating in organised physical activity. The findings emphasise the importance of sport-specific training in enhancing different aspects of motor coordination and highlight the need for tailored training interventions for different types of sports.

Participants involved in ball sports demonstrated superior eye-foot coordination, as shown by significantly lower reaction times compared to both the rhythmic sports and inactive groups. The large effect size (d = 2.02) between ball sports and rhythmic sports suggests that ball sports training, which emphasises rapid visual processing and motor responses, leads to substantial improvements in reaction time and visual-motor integration. This advantage is critical in sports like basketball and soccer, where split-second decisions and quick reflexes are key to successful performance [3, 4]. The moderate effect size (d = 1.47) between ball sports and inactive groups further supports the role of ball sports in enhancing coordination skills beyond general physical activity.

The rhythmic sports group also outperformed the inactive group in eye-foot coordination, despite primarily training with auditory stimuli. This suggests a cross-modal transfer effect, where the motor skills developed through rhythmic sports training (e.g., timing and synchronisation) positively impact visual-motor tasks such as eye-foot coordination. Cross-modal transfer – the idea that training in one sensory modality can enhance performance in another – is supported by several studies. Bläsing et al. [19] found that training in rhythmic dance improves general motor coordination, indicating that auditory-motor tasks can have broader motor benefits. Cornejo et al. [12] also demonstrated that cross-modal coordination between auditory and visual stimuli enhances motor performance. The moderate effect size (d = 0.72) between rhythmic sports and inactive groups supports the notion that rhythmic training can contribute to visual-motor improvements, even when the primary training stimuli are auditory.

In the ear-foot coordination test, rhythmic sports participants outperformed both ball sports participants and inactive individuals, as evidenced by significantly lower CV_{ITI} scores. The moderate effect size (d = 1.24) between rhythmic sports and ball sports emphasises the importance of rhythmic sports training in enhancing auditory-motor synchronisation, which is crucial for success in sports like artistic swimming and rhythmic gymnastics [18, 20]. The ability to coordinate movements precisely with auditory cues highlights the sport-specific nature of these motor skills, which may not fully transfer to ball sports, where visual cues are more dominant [3].

Interestingly, ball sports participants performed worse than rhythmic sports participants in ear-foot coordination. While ball sports athletes benefit from visual-motor training, their auditory-motor skills may not be as well-developed due to the lower emphasis on auditory cues in their training. This finding suggests that while there is potential for cross-modal transfer, its effectiveness depends on the specific sensory demands of the sport [10]. Practical implications from this finding suggest that incorporating rhythm-based exercises or auditory-motor synchronisation drills into ball sports training could help improve these coordination aspects.

Moreover, it is important to consider that the differences observed between the groups may not be solely due to training but could also be influenced by natural predispositions, such as genetic factors. Research suggests that some individuals may have innate motor abilities – such as faster reaction times or superior spatial awareness – that predispose them to excel in specific sports [21, 22]. These predispositions may influence both the type of sport athletes engage in and their performance. Nevertheless, training remains critical in developing motor coordination, as demonstrated by the significant differences observed between trained and inactive individuals. Future studies should assess the participant's baseline motor skills or explore genetic factors contributing to their performance in various sports.

The inactive group, consisting of adolescents who did not regularly engage in organised physical activity, exhibited the lowest performance in both eye-foot and ear-foot coordination tests. This finding supports previous studies highlighting the importance of regular physical activity and sports participation in enhancing motor skills and overall physical development [1, 2]. Adolescents who do not participate in regular physical activity often miss out on critical periods of motor development and the associated cognitive and social benefits [2, 23]. The lower coordination scores in the inactive group underscore the need to promote regular physical activity and diverse sports participation among adolescents to foster motor development. Inactivity during adolescence can lead to long-term deficits in motor skills and physical fitness, which may persist into adulthood [23, 24]. Furthermore, Telama et al. [25] suggested that physical inactivity during adolescence is linked to lower physical activity levels in adulthood, emphasising the importance of early engagement in sports.

The significant differences observed between the groups underscore the need for tailored training programs that address the specific motor demands of different sports. For ball sports athletes, drills focusing on reaction time, agility, and visual-motor integration are essential for improving eye-foot coordination. Conversely, rhythmic sports athletes would benefit from exercises enhancing auditory-motor synchronisation, such as rhythm-based drills and coordination tasks with auditory cues. Integrating elements from both types of training into general physical education programs could offer a more holistic approach to motor skill development, ensuring the students develop a broad range of coordination skills essential for various physical activities [11, 26].

While this study provides valuable insights into the impact of sport-specific training on motor coordination, several limitations should be acknowledged. First, the sample size was relatively small, potentially limiting the generalizability of the findings. A larger sample size would provide more statistical power and allow for a more nuanced understanding of the differences between groups. Second, the study's cross-sectional design limits the ability to draw causal inferences. A longitudinal design would provide greater insight into how motor coordination develops over time and the long-term effects of different sports training. Third, the study focused on adolescents aged 12–15, which limits the applicability of the findings to other age groups. Previous research has shown that motor coordination develops differently across age groups [1, 23]. Future studies should include a broader age range to assess how these patterns vary throughout developmental stages. Finally, individual differences in baseline motor skills, previous sports experiences, and engagement in non-sport activities were not controlled for, which may have influenced coordination performance. The study also focused on two types of sports (ball and rhythmic), which may limit the applicability of the findings to other sports, such as martial arts or cycling, which rely on different types of coordination.

Conclusions

This study highlights the significant impact of sport-specific training on motor coordination development in adolescents. Ball sports enhance eye-foot coordination, while rhythmic sports improve ear-foot coordination, underscoring the specific motor demands of each sport. Based on these findings, tailored training programs should focus on improving reaction times and visual-motor integration in ball sports, and auditory-motor synchronisation in rhythmic sports. Additionally, the potential for cross-modal transfer – where skills in one modality enhance performance in another – emphasises the importance of incorporating diverse stimuli into training. By understanding the unique coordination needs of different sports, coaches can design effective training regimens that enhance athletic performance and overall physical competence in adolescents.

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Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Chulalongkorn University (approval No.: 650196).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Conflict of interest

The authors state no conflict of interest.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

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