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Sex and lateral dominance effects on learning a complex gymnastic skill

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Abstract

Background and Study Aim The development of motor skills is influenced by various biological and biomechanical factors. Among these, sex-based characteristics and lateral dominance are known to shape movement strategies and performance outcomes. Despite the use of different training approaches to accommodate these factors, their relative effectiveness in promoting symmetrical motor skill acquisition remains a matter of practical interest. This study investigated whether sex and limb dominance affect the learning of a cartwheel on both the dominant and non-dominant sides. It also assessed whether performance progression differs between males and females for each execution side.

Material and Methods A total of 145 second-year kinesiology students participated in the study (males: N = 89, age 20.95 ± 1.17 years; females: N = 56, age 20.55 ± 0.97 years). Participants were divided by sex and dominant performance side. They practiced the cartwheel at five measurement points. Performance was evaluated using a standardized expert-rating protocol. A three-way mixed-design 2×2×5 ANOVA tested the main effects of sex (male vs. female), performance side (dominant vs. non-dominant), and measurement point (initial – Week 7; first transitional – Week 10; second transitional – Week 13; final – Week 15; retention – two weeks post-learning). Bonferroni post hoc correction was applied when needed. Effect sizes were calculated using partial eta-squared (ηp^2).

Results A significant main effect of measurement was found ($p < 0.001$; $\eta p^2 = 0.101$), confirming skill acquisition over time. The main effect of sex was not significant ($p = 0.074$; $\eta p^2 = 0.068$). However, the interaction between sex and measurement was significant ($p < 0.001$; $\eta p^2 = 0.072$), indicating sex-specific learning patterns. Post hoc analysis showed that females improved more rapidly and reduced side asymmetry over time. Males progressed more gradually and maintained a performance advantage on the dominant side

Conclusions Sex and lateral dominance affect how complex motor skills are acquired. The results suggest a need for individualized instructional strategies in motor learning.

Keywords: motor learning, gymnastics, sex differences, laterality, skill acquisition, performance asymmetry

Introduction

Human motor behavior is shaped by both innate biological structures and adaptive processes. Among the most visible expressions of this is manual lateralization, commonly known as handedness. Lateral dominance, particularly the preference for using one hand over the other, reflects underlying neural asymmetries that influence motor performance and coordination. This asymmetry is not merely a characteristic of preference but a functional element that affects how motor skills are learned and executed in everyday and sport-specific contexts.

This phenomenon is exemplified by the widespread prevalence of right-handedness in the general population, with manual lateralization recognized as one of the most prominent behavioral asymmetries in humans [1, 2]. Approximately 90 percent of individuals prefer using their right hand, while the remaining population either favors the left or shows no strong preference (ambidexterity). The biological basis of bodily lateralization stems from the evolutionary specialization of the left hemisphere for motor functions and brain lateralization processes associated with complex motor control [3, 4, 5]. Although it was historically assumed that left-handed individuals exhibit reduced cerebral lateralization, meaning that certain cognitive and motor processes are more evenly distributed between the hemispheres, recent findings in motor behavior research indicate that motor asymmetries are largely comparable between left- and right-handed individuals [6, 7]. Once hand dominance develops, it rarely changes across the lifespan [8]. The stability and prevalence of lateral dominance play a key role in motor learning and task performance, as the preferred limb typically demonstrates superior motor performance [1].

Lateralization is not merely an individual characteristic. It also has a substantial influence on motor skill acquisition and the execution of motor tasks [1, 9, 10]. The dominant limb generally exhibits greater coordination and precision. In

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contrast, the non-dominant side may progress more slowly when learning complex motor skills [10, 11]. Neurophysiological evidence indicates that performance asymmetry between limbs correlates with differences in cortical representation. This supports the role of lateralization in motor control processes [12]. Some studies suggest that lateralization does not necessarily impede skill acquisition with the dominant limb. Nor does it always hinder the transfer of skills to the non-dominant side, particularly in low-complexity tasks [13].

The concept of handedness is closely related to the notion of ambidexterity. Ambidexterity refers to the ability to use both hands with equal skill. This trait is extremely rare and occurs in approximately 1 percent of the population [14]. Most individuals considered ambidextrous develop this ability through practice or adaptation, especially in environments where right-hand use is predominant [15, 16]. This suggests that ambidexterity is often not an innate trait but rather the result of motor learning and training [16]. Although it may be linked to certain neurological characteristics, such as relatively symmetrical hemispheric functioning, ambidexterity is often confused with mixed-hand dominance. This confusion can affect the accuracy of prevalence estimates [14, 15, 16]. Symmetrical hemispheric functioning may provide some advantages in motor task execution. However, differences in lateralization remain a key factor in individual performance [14].

The nature of ambidexterity is important in motor learning research, as hand dominance and lateralization affect the acquisition and execution of motor skills. When planning and analyzing motor tasks, it is necessary to consider not only the dominant hand of participants but also the potential for adaptation or acquired ambidexterity through practice and training [15, 16]. Castañer et al. [17] found that athletes with ambidexterity demonstrated better balance and movement symmetry, which positively influenced performance in sports games. Sánchez-Rodríguez et al. [18] showed that ambidexterity can be developed through specific motor training, improving sport skills in children aged 9 to 12. However, ambidexterity is not always associated with positive outcomes. Children with mixed-hand dominance are more likely to experience language-learning difficulties, mental health challenges, and academic problems compared to left- or right-handed children [19, 20]. Ambidexterity may have varied effects on motor learning and performance depending on the context and environment.

In addition to lateralization, sex may also be an important factor in motor learning. Children of different sexes often show distinct patterns in the development of coordination, strength, and motor task execution speed [21, 22]. Differences in the rate of motor learning between boys and girls are relevant to understanding how motor skills develop over time. While some performance disparity is observed in early developmental stages, these differences tend to evolve, particularly during adolescence [23, 24]. Boys often perform better in gross motor skills. In contrast, girls tend to demonstrate advantages in fine motor control. However, these distinctions are not absolute and may be shaped by social, cultural, and educational factors.

Motor learning also varies with age. Children exhibit greater neuroplasticity and benefit from more efficient sleep-related consolidation. This supports better long-term retention of motor skills. Adults, on the other hand, may acquire movements more quickly due to greater muscular strength, coordination, and accumulated experience [25, 26, 27]. Neurological and sensorimotor differences further influence learning strategies. Children rely more on proprioceptive and somatosensory feedback, whereas adults depend more on vestibular input and cognitive control mechanisms [25, 28]. These developmental and strategic distinctions have important implications for designing motor learning programs. They emphasize the need to adapt teaching methods and training intensity to the learner's stage of development.

Analysis of research findings has shown that both lateral dominance and sex-related differences significantly influence motor learning processes, affecting the rate, symmetry, and retention of acquired skills. Researchers emphasize that these factors interact with neurodevelopmental and biomechanical variables, shaping individual learning trajectories across age groups and task complexities. At the same time, the practical application of these insights in educational and training environments continues to face limitations, particularly regarding the personalization of motor instruction. This ongoing gap complicates the design of effective teaching strategies for complex motor skills and highlights the need for further structured exploration of how sex and lateral dominance interact during the acquisition of bilateral movement tasks.

Guided by this theoretical rationale, the present study aimed to examine the effects of sex and lateral dominance on the acquisition of a complex gymnastic skill, the cartwheel, and to determine whether learning progress differs between males and females across dominant and non-dominant execution sides.

It was hypothesized that:

– Performance on the dominant side would be superior to that on the non-dominant side across all measurement points.
– Female participants would demonstrate faster and more symmetrical improvement in cartwheel performance compared to male participants.
– The asymmetry between dominant and non-dominant sides would decrease over time as a

result of motor learning and bilateral transfer.
– An interaction between sex and performance side was expected, such that females would reduce asymmetry more rapidly than males.

Materials and Methods

Participants

Following guidelines described in the scientific literature [30] and using G*Power v3.1 software (University of Bonn, Germany), the required sample size was estimated with type I error $\alpha = 0.05$, type II error $\beta = 0.20$, and an expected effect size of 0.15. Based on research reporting performance scores in comparable variables [31, 32], the necessary sample size was estimated to range between 44 and 78 participants. The final sample consisted of N = 145 second-year kinesiology undergraduate students (males: N = 89, age M ± SD = 20.95 ± 1.17; females: N = 56, age M ± SD = 20.55 ± 0.97). Participants attended the study over a 15-week period, with two sessions per week. Each session lasted for two school hours. Participation was entirely voluntary, with the option to withdraw at any time without consequences. Participants were informed that results would be reported only at the group level to ensure anonymity. Individuals with current or recent (within six months) injuries or medical conditions affecting motor performance were excluded. During the study, 16 participants were removed due to incomplete participation across all measurement phases. The study was conducted in full accordance with the Declaration of Helsinki. The research was approved by the Institutional Ethics Committee (approval number: 2181-205-02-05-25-008).

Research Design

The research aimed to analyze the learning process of a complex motor skill that can be performed on both sides of the body. This movement structure allows for the examination of the influence of lateral dominance on motor learning. The cartwheel was selected as the target skill, as previous studies [31, 32] have classified it as a complex motor task requiring coordination, strength, balance, and spatial orientation. It can be executed on both the dominant and non-dominant sides.

Correct execution involved starting from an upright stance with arms raised. The participant stepped forward with the lead leg, flexed the trunk, and simultaneously rotated the torso 90 degrees while swinging the legs. This was followed by sequential placement of the same-side and opposite-side hands on the ground. The movement passed through a handstand with leg separation, shifted weight to the second hand, and rotated 90 degrees around the longitudinal axis. Upon contacting the ground with the lead foot, the participant pushed off with an arm swing, raised the trunk, and finished in an upright position with arms raised. All support points had to align along an imaginary straight line. Table 1 presents the assessment criteria used to evaluate task performance.

Prior to the commencement of the experimental protocol, participants were informed about the nature of the study, task specifics, data

Table 1. Criteria for evaluating the performed motor task - Cartwheel

Score	Performance Description
5 – Excellent	The participant performs the cartwheel from a frontal starting position without any errors.
4 – Very Good	The participant performs the cartwheel from a frontal starting position with: • minor errors in the initial and final position • slight lack of full-body tension
3 – Good	The participant performs the cartwheel from a frontal starting position with: • more pronounced errors in the initial and final position • noticeable flexion/tension in the legs and arms during execution • minor deviations from the vertical axis of movement • minor deviations from movement along a straight line
2 – Sufficient	The participant demonstrates basic understanding of the cartwheel structure from a frontal starting position, but execution shows: • major errors in the initial and final position • small distance between the stepping/take-off leg and the first hand placed on the ground • pronounced flexion/tension in the legs and arms • large deviations from the vertical axis of movement • large deviations from movement along a straight line
1 – Insufficient	The participant is unable to independently perform the cartwheel from a frontal starting position.

collection procedures, and the importance of consistent attendance during recording sessions. Confidentiality and privacy were ensured through pseudonymization with ID codes, separate storage of personal data and video recordings, and restricted access for the research team only.

Participants were explicitly instructed not to engage in any additional practice of the cartwheel outside the scheduled training sessions. Compliance was monitored through weekly self-report declarations and informal instructor check-ins.

The experiment was conducted in an indoor sports hall under controlled environmental conditions (air temperature 21 °C). During regular morning class sessions, participants wore fitted sports clothing and socks. They completed a standardized warm-up (5 to 7 minutes) before beginning the cartwheel learning process from a frontal starting position. The same evaluator provided instruction throughout the study.

During practice, participants received immediate verbal feedback focused on errors in key execution phases. This approach followed prior findings indicating that correcting key errors is more effective for acquiring complex motor skills than addressing all observed errors [33].

Motor skill performance was organized in two sets. The first was performed toward the dominant side and the second toward the nondominant side, based on each participant's self-selected preferred side. Each set consisted of two series of five repetitions, with a short rest between series.

For recording purposes, each participant performed one cartwheel on the dominant side and one on the nondominant side. Performance was recorded at five time points: initial (Week 7), first transitional (Week 10), second transitional (Week 13), final (Week 15), and retention (two weeks post-learning). The recordings were evaluated by four qualified gymnastics judges who had been trained and standardized in the assessment criteria and scoring procedures.

Statistical Analysis

Psychometric characteristics of the applied measurement instruments were analyzed for the entire participant sample. Scoring reliability was assessed using average inter-item correlation (IIR), and internal consistency was evaluated with Cronbach's alpha coefficient (Cα). Measurement reliability was further analyzed using the intraclass correlation coefficient (ICC). Total performance score was calculated as the sum of scores for both left- and right-side executions for each experimental group and each measurement occasion. Descriptive statistics included the arithmetic mean (M), standard deviation (SD), skewness (SKEW), kurtosis (KURT), and minimum (MIN) and maximum (MAX) values. To examine group and performance differences, a three-way mixed design ANOVA (2 × 2 × 5) was used. The factors were Sex (between-subject), Performance Side (within-subject), and Measurement (within-subject). Bonferroni post hoc correction was used to identify specific differences. The assumption of sphericity was tested for the Measurement factor, and when violated, the Greenhouse–Geisser correction was applied. F-values and significance levels (p) were reported. Partial eta squared (ηp^2) was used as the effect size indicator and interpreted as small if < 0.06, moderate if 0.06–0.15, and large if ⩾ 0.15. Type I error was set at $\alpha = 0.05$. All analyses were conducted in Statistica 14 (Cloud Software Group, Inc., Palo Alto, CA, USA, 2023).

Results

Table 2 presents the results of the reliability and homogeneity analysis.

Table 2. Reliability and homogeneity results

Results	ICC	Cα	IIR
1-L	0.971	0.973	0.910
1-R	0.969	0.971	0.900
2-L	0.936	0.941	0.816
2-R	0.956	0.960	0.872
3-L	0.942	0.944	0.821
3-R	0.960	0.964	0.879
4-L	0.921	0.922	0.765
4-R	0.949	0.949	0.836
5-L	0.930	0.933	0.786
5-R	0.949	0.951	0.839

Note: 1–5 = measurement points; L = left side performance; R = right side performance; ICC = intraclass correlation coefficient; Cα = Cronbach's alpha coefficient; IIR = average inter-item (judge) correlation.

Table 2 clearly demonstrates high reliability of the measurement procedure. This is confirmed by very high ICC values, Cronbach's alpha coefficients, and average inter-item correlations across all assessment points. These findings indicate strong consistency in evaluations and stability of the applied measurement instruments.

Furthermore, Figure 1 displays the distribution of dominant execution side in cartwheel performance with respect to sex. The figure visually illustrates patterns of lateral dominance in the examined sample.

In both sexes, the dominant execution of the cartwheel most frequently involved stepping into the left side, with the right hand serving as the dominant hand at the moment of take-off from the ground. This pattern confirms a pronounced right-hand preference in the examined sample. Analysis of left-side vs. right-side dominant executions further showed that the percentage of left-dominant individuals was lower among males than among females.

Table 3 presents descriptive statistics of the results by sex, dominance side, and individual measurement points. It provides detailed insight into performance patterns and variability within the observed groups.

Analysis of the learning curves revealed consistent performance improvements across all groups (Figure 2). Females achieved higher mean scores on the dominant side at all time points, with the most marked improvement occurring

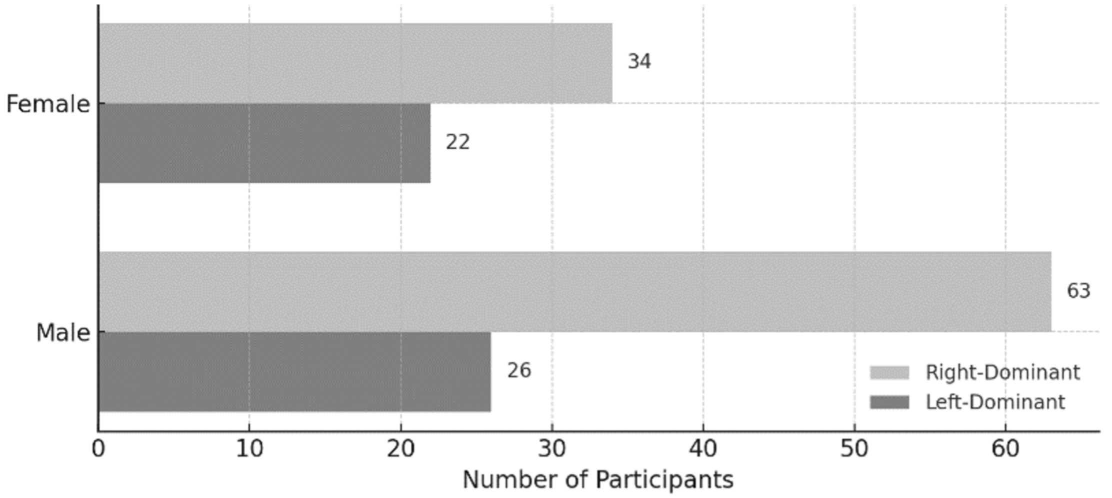

Figure 1. Dominant side distribution in cartwheel execution

Table 3. Descriptive statistics of results by sex, dominance side, and measurement points (1–5)

Assessment Point	Dominant Leg	Performance Leg	Male Students					Female Students				
			N	M ± SD	Min–Max	Skew	Kurt	N	M ± SD	Min–Max	Skew	Kurt
1	R	L	26	2.59±1.35	1.00-4.38	-0.04	-1.84	22	2.53±1.21	1.00-4.75	0.10	-1.07
1	R	R	26	3.54±0.87	1.00-4.63	-1.43	1.94	22	3.83±0.62	2.50-5.00	-0.10	0.31
2	R	L	26	3.24±1.13	1.00-4.88	-0.45	-1.10	22	3.36±0.79	1.50-4.75	-0.50	-0.04
2	R	R	26	3.55±0.89	1.25-4.88	-1.00	0.83	22	3.99±0.75	2.50-5.00	-0.63	-0.25
3	R	L	26	3.45±1.12	1.00-5.00	-1.07	0.44	22	3.59±0.63	2.25-4.75	-0.53	-0.26
3	R	R	26	3.75±0.91	1.25-5.00	-1.18	1.21	22	4.29±0.58	3.13-5.00	-0.19	-0.98
4	R	L	26	3.75±0.99	1.00-5.00	-1.31	1.52	22	3.98±0.53	2.75-4.75	-0.91	1.02
4	R	R	26	3.87±0.88	1.25-5.00	-1.39	2.36	22	4.35±0.60	3.13-5.00	-0.45	-1.02
5	R	L	26	3.74±1.06	1.00-5.00	-1.42	1.94	22	4.18±0.57	3.00-5.00	-0.09	-0.63
5	R	R	26	3.93±0.89	1.25-5.00	-1.44	2.53	22	4.44±0.57	3.13-5.00	-0.75	-0.29
1	L	L	63	3.52±0.84	1.00-4.75	-1.27	1.35	34	3.43±1.40	1.00-5.00	-0.74	-0.85
1	L	R	63	2.78±1.10	0.88-4.63	-0.30	-1.10	34	2.78±1.47	1.00-5.00	0.09	-1.50
2	L	L	63	3.49±0.82	1.25-4.75	-1.09	0.59	34	3.81±1.01	1.25-5.00	-0.84	0.09
2	L	R	63	3.17±0.88	1.00-4.25	-0.88	-0.01	34	3.32±1.34	1.00-5.00	-0.54	-0.83
3	L	L	63	3.72±0.71	1.25-4.75	-1.32	1.86	34	3.94±0.95	1.50-5.00	-0.93	0.23
3	L	R	63	3.42±0.83	1.00-4.50	-1.14	0.80	34	3.54±1.24	1.00-5.00	-0.87	-0.09
4	L	L	63	3.94±0.54	2.50-5.00	-0.91	0.67	34	4.19±0.82	2.00-5.00	-1.09	0.60
4	L	R	63	3.59±0.79	1.00-5.00	-1.18	1.53	34	3.88±1.15	1.00-5.00	-1.33	1.41
5	L	L	63	3.86±0.58	2.00-4.63	-1.37	1.99	34	4.17±0.88	2.00-5.00	-1.04	0.08
5	L	R	63	3.65±0.74	1.50-5.00	-1.41	1.90	34	4.01±1.07	1.00-5.00	-1.35	1.86

Note: Assessment Point (1–5) = measurement number; Dominant Leg = participant's preferred leg for initiating the cartwheel; Performance Leg = side (left or right) on which the cartwheel was performed; L = left-side performance; R = right-side performance.

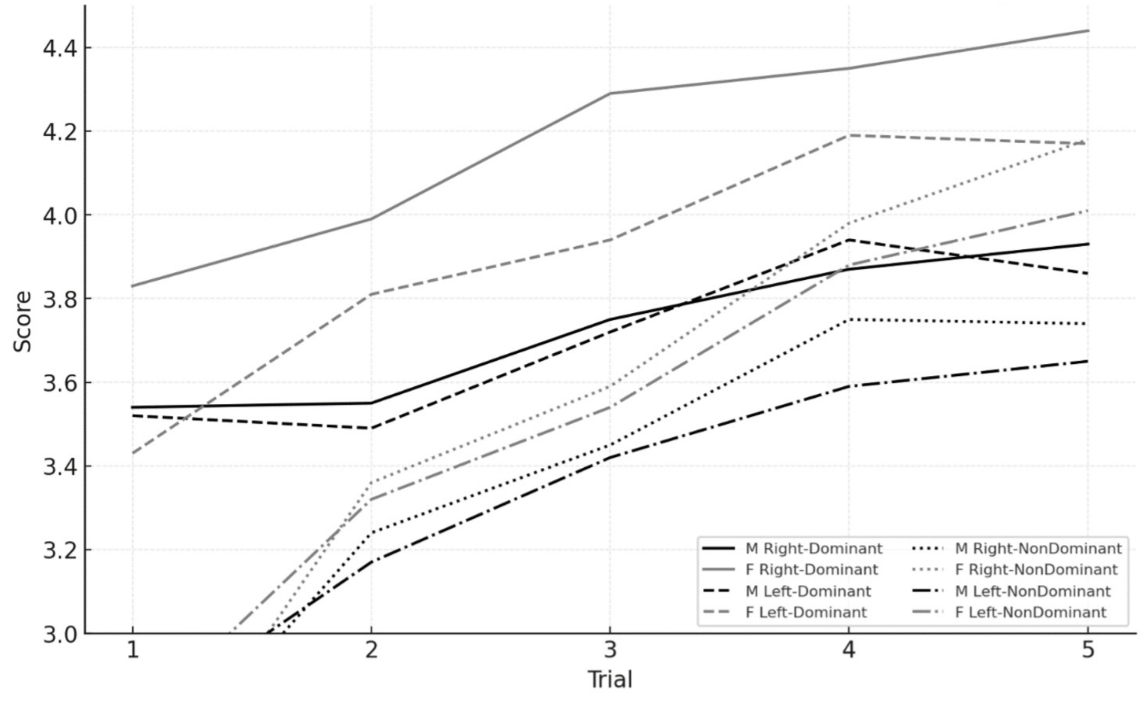

Figure 2. Learning dynamics of the cartwheel; differences according to measurement point, sex, and execution side

between the second and third measurements. Male progression was more gradual. Performance on the non-dominant side also improved for both sexes, albeit with greater trial-to-trial variability. A performance advantage for the dominant side was evident throughout the study, but this asymmetry diminished over time—a trend more pronounced in female participants.

Figure 2 illustrates the progression of cartwheel learning across the five measurement points, highlighting differences by measurement occasion, sex, and execution side.

Analysis of the learning curves demonstrated a consistent improvement in cartwheel performance across all groups over the five measurement points (Figure 2). On the dominant side, both males and females showed continuous progress, with females achieving higher average scores throughout the entire period and exhibiting the most pronounced improvement between the second and third measurements. In males, improvement was more gradual, with a slight plateau between the first and second measurements. On the non-dominant side, performance also increased over time, though with somewhat greater fluctuations compared with the dominant side. Across both sexes, performance was consistently better on the dominant than on the non-dominant side at all time points, with females displaying a more pronounced initial difference between sides, whereas males showed a more moderate but persistent side difference throughout the entire testing period. The overall difference between dominant and non-dominant sides gradually decreased as learning progressed.

The significance of the effects of measurement point, sex, and execution side was examined using a three-way factorial ANOVA (Table 4).

Table 4. Three-way mixed design ANOVA: main and interaction effects

Effect	**F**	**p**	**η^2**
Sex	3.237	0.074	0.068
Measurement	121.812	<0.001	0.101
Measurement × Sex	5.056	<0.001	0.072
Performance Side	1.95	0.165	0.006
Performance Side × Sex	2.714	0.102	0.054
Measurement × Performance Side	0.477	0.753	0.002
Measurement × Performance Side × Sex	1.188	0.315	0.023

Note: F = value of the F-test; p = level of statistical significance; η^2 = partial eta squared as an effect size measure.

The repeated-measures ANOVA (Table 4) revealed a statistically significant main effect of measurement, indicating systematic changes across the time points. Although the main effect of sex did not reach statistical significance, a significant interaction between sex and measurement was found. The interaction between measurement and performance side, as well as the three-way interaction between measurement, performance side, and sex, were not statistically significant.

Discussion

This study aimed to examine the effects of sex and lateral dominance on the acquisition of a complex gymnastic skill, the cartwheel. It also investigated whether learning progress differs between males and females across dominant and non-dominant execution sides.

The psychometric properties of the applied instruments indicated that the measurement procedure was reliable and internally consistent. These findings support its appropriateness for assessing motor skill development. While the current evaluation system proved adequate, further refinement of assessment tools may enhance scientific validity and promote broader application in educational and sport-training contexts. In physical education settings, dependable and objective evaluation allows instructors to track learner progress, detect motor difficulties early, and adjust teaching methods to individual needs.

This study also examined patterns of lateral dominance to identify specific characteristics of motor performance. In both sexes, the cartwheel was most frequently executed by stepping into the left side, with the dominant right hand supporting during take-off. This pattern confirms a strong right-hand preference in the examined sample and aligns with previous research showing a high prevalence of right-handedness in the general population [34, 35]. The distribution of lateral preference revealed that left-dominant execution was less common among males than females. Among the 89 male students, 63 (approximately 71%) performed to the left (right-hand dominant) and 26 (29%) to the right. Among the 56 female students, 34 (60%) performed to the left and 22 (40%) to the right. These findings contrast with the meta-analysis by Papadatou-Pastou et al. [34], which reported that men are 23% more likely than women to be left-handed. This discrepancy may reflect population-specific factors, including cultural or environmental influences on lateral preference [2, 34, 36].

Descriptive indicators showed that performance on the dominant side, particularly among female participants, was higher and exhibited more stable improvement than on the non-dominant side. Among males, side-based differences were more pronounced and accompanied by greater variability within the group. These findings indicate that sex may influence the dynamics of motor skill acquisition. Female participants demonstrated more consistent learning patterns, whereas male participants showed greater individual differences in performance. This corresponds with earlier studies reporting that female gymnasts often acquire technical elements more quickly and with greater stability in execution [37].

Learning-curve analysis showed a gradual reduction in performance differences between dominant and non-dominant sides over the course of practice. Female participants demonstrated faster and more stable progress, achieving near-complete symmetry by the retention phase. This pattern is consistent with the findings of Zolfaghari, Zareian, and Salman [38], who reported that higher task complexity prolongs acquisition and consolidation in motor learning. The symmetry observed among women at retention suggests strong consolidation of motor memory. In contrast, male participants retained noticeable side differences throughout most phases, showing smaller reductions and residual asymmetry at retention. According to the framework proposed by Schmidt and Lee [39], in which stable retention reflects more robust learning, these results suggest stronger skill stabilization in women and a slower, less consistent consolidation process in men.

Previous research also shows that motor learning involves progressive stabilization and a gradual equalization between body sides over time [40, 41]. Findings from gymnastics studies support faster acquisition and greater execution stability among females [40, 41, 42]. Research on lateral dominance confirms that initial side preferences tend to diminish with practice, as motor programs become more consolidated [6]. Consistent with this, female participants in the present study equalized performance across sides earlier, while male participants showed slower and less consistent improvement. The results of the repeated-measures three-factor ANOVA further support these trends. Time and its interaction with sex significantly influenced learning dynamics. Although sex alone did not have a statistically significant effect on mean scores, the interaction between sex and measurement revealed different patterns of change for males and females. These results indicate that sex modulates the progression and consolidation of motor learning, without serving as an independent predictor of performance. This interpretation is consistent with earlier studies reporting sex-related differences in learning rate, movement stability, and execution quality [37, 40].

Limitations of the Study

This study examined the interaction between sex, lateral dominance, and motor learning of a complex gymnastic skill. Several limitations should be considered. First, the sample included only kinesiology students with prior exposure to motor-learning environments, which may limit the generalizability of the findings to other populations, such as children or individuals without athletic backgrounds. Second, performance was assessed using expert observational ratings. Although reliability indices were high, this method may still be affected by subjective interpretation and minor measurement variability. Third, only one specific motor skill (the cartwheel) and one instructional approach were used, which restricts the applicability of the findings to other motor tasks or teaching methods. Finally, the study design does not permit causal conclusions about the neurophysiological mechanisms underlying the observed differences.

Future Research Directions

Future studies should include participants with varying ages, skill levels, and physical backgrounds to strengthen external validity. The use of objective measurements, such as kinematic or electromyographic data, may provide greater insight into the neuromuscular mechanisms underlying learning asymmetries. Further research should also explore different instructional formats, including digital, augmented, or mixed-modality feedback, and how these approaches interact with sex and lateral dominance. Longitudinal studies focusing on retention and transfer of learned skills to other motor tasks would support a more complete understanding of motor learning over time. Additionally, examining psychological variables such as motivation, self-efficacy, and attentional focus may help explain individual differences in learning processes and outcomes.

Conclusions

The results of this study showed that sex and lateral dominance influenced the process of learning a complex motor skill. Female participants demonstrated faster improvement and a greater reduction in performance asymmetry between sides. In contrast, male participants progressed more gradually and showed greater variability, with asymmetry decreasing more slowly and less consistently. These outcomes suggest that motor learning dynamics may differ by sex and preferred execution side, which should be considered in the evaluation and instruction of bilateral motor tasks.

The applied assessment instruments exhibited stable reliability across all phases. However, observed scoring fluctuations indicate a need for refining evaluation procedures to reduce variability and improve precision. Such refinements may benefit not only research validity but also instructional practice, where accurate performance monitoring is essential for adjusting teaching strategies.

Conflict of Interest

The authors declare no conflict of interest.

AI Tools Usage

The authors used *ChatGPT-5* (OpenAI) exclusively for language polishing, grammar correction, and minor phrasing adjustments. The tool was not used for generating original scientific content, data analysis, or interpretation of results. All intellectual and analytical contribution are the sole responponability of the authors.

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