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Cite this article: Simon T, Loffing F, Frasnelli E. 2026 Thrown off balance: left-handers are under-represented in elite throwing sports. *R. Soc. Open Sci.* **13**: 251982.
https://doi.org/10.1098/rsos.251982

Received: 15 October 2025
Accepted: 18 November 2025

Subject Category:
Psychology and cognitive neuroscience

Subject Areas:
behaviour, psychology

Keywords:
laterality, left-handedness, track and field, non-antagonistic sports, throwing

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Supplementary material is available online at https://doi.org/10.6084/m9.figshare.c.8207384.

THE ROYAL SOCIETY
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Thrown off balance: left-handers are under-represented in elite throwing sports

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Compared to the approximately 10% prevalence of left-handers in the general population, left-handedness is over-represented among athletes in various antagonistic, duel-based sports, such as combat sports (e.g. fencing) and interactive ball games (e.g. table tennis). This over-representation is considered indirect evidence of a competitive advantage, often attributed to right-handers' unfamiliarity with left-handed opponents' action patterns and/or to superior neuropsychological and motor control abilities among left-handed athletes. While extensive research has examined left-handedness in antagonistic sports, its impact in non-antagonistic disciplines—where direct interactive contests are absent—remains largely underexplored. To address this gap, we analysed left-hander prevalence among over 6000 elite track-and-field athletes ranked in year-end world rankings (2005–2024) across javelin throw, discus throw and shot put. Handedness was determined by athletes' functional hand used for sport performance, i.e. their throwing or putting hand. Our findings reveal a striking under-representation of left-handed athletes in all three disciplines (approx. 2–5%), for both female and male athletes, compared to the approximately 10% prevalence in the general population. While left-handedness may confer advantages in certain antagonistic sports, our findings suggest it may pose disadvantages in non-antagonistic contexts. We discuss several factors potentially contributing to this pattern.

1. Introduction

Handedness represents the most extensively studied form of behavioural asymmetry in humans and can refer to both individuals' *preference* for using one hand over the other and to their relative hand *skill* [1]. In empirical research, hand preference is typically assessed using standardized self-report instruments such as the Edinburgh Handedness Inventory (EHI), which records preferred hand use for 10 or more daily activities, including writing, drawing, cutting with scissors or brushing teeth [2]. Relative hand skill, by contrast, can be measured using performance-based protocols that compare, for instance, the two hands' speed, strength, and precision in specific manual activities [3–5].

Across regions of the world, right-handedness predominates, whereas left-handedness occurs only in a minority of individuals, with its global prevalence estimated at around 10% [6]. However, in various sports, left-handed athletes are frequently found at higher rates than the approximately 10% baseline prevalence of left-handedness in the general population. Studies investigating handedness in sports typically determine athletes' handedness based on sport-specific preferential hand use (e.g. [7–9]). In sports requiring unilateral use of one hand for sport-specific actions, such as using a one-handed weapon or striking a ball with a racket, athletes who rely on their left or right hand for these actions would be regarded as left- or right-handed, respectively. The functional hand used for such sports is usually consistent with an athlete's everyday hand preference, commonly measured with instruments like the EHI [10]. Although functional hand use in sports may also reflect relative manual skill, we treat it primarily as a preference-based measure and, unless otherwise stated, use the term 'handedness' chiefly to refer to hand preference throughout this work.

Over-representation of left-handed athletes has been most evident in unimanual sports characterized by antagonistic, duel-like interactions, such as combat sports. In fencing (foil), up to 34% of elite athletes ranked in the top 50 of recent year-end world rankings over the past two decades wielded the weapon with their left hand [9]. In boxing, 12.5% of professional female boxers and 17% of male boxers in 2019 adopted the 'southpaw stance', characterized by positioning the right leg and shoulder closer to the opponent [11]. This stance is commonly advised for boxers who have a stronger left hand, as it allows for more powerful left-handed punches. A high prevalence of left-handers has also been reported in fast interactive ball sports. For instance, in table tennis, up to 30% of athletes ranked in the top 50 of recent year-end world rankings over the last 20 years used their left hand to hold the racket [9].

The over-representation of left-handed athletes is considered indirect evidence of a competitive advantage [12–14]. The most widely accepted explanation for this phenomenon is the *negative frequency-dependent advantage hypothesis* (*NFDA*). According to this hypothesis, in antagonistic contests, left-handers benefit from their rarity in the population: opponents are less familiar with left-handed action patterns, giving left-handers an element of surprise [13,15,16]. Negative frequency-dependent selection, a core concept in evolutionary biology, posits that the fitness of a trait decreases as it becomes more common and increases when it is rare. Applied to sports, *NFDA* predicts that the less frequently athletes encounter left-handers, the greater their advantage—an advantage that diminishes as left-handers become more common and opponents gain experience.

Apart from *NFDA*, left-handed athletes may also enjoy a performance advantage independent of their frequency or opponents' experience, a hypothesis often referred to as the *innate superiority hypothesis* (*IS*) [14]. According to *IS*, certain frequency-independent traits potentially linked to left-handedness may confer performance benefits in sports. For example, left-handers might gain an advantage from functional specializations of the brain's right hemisphere [14]. Specifically, motor actions executed with the left hand are predominantly governed by the right hemisphere, which plays a leading role in visuospatial, spatiotemporal and visuomotor processing [17–21]. In sport-specific tasks that rely on these abilities, neural processing may be more efficient for left-hand movements than for right-hand movements, potentially because of reduced information transfer delays [22–24]. In contrast, right-hand actions, primarily controlled by the contralateral left hemisphere, require cross-hemispheric communication via the corpus callosum, which could introduce minor delays affecting performance in time-sensitive situations [17,25,26]. Right-hemisphere specialization has also been suggested to support superior control in precision-based sports movements, including aiming activities like fencing [17,27,28] and in close-range object manipulation typical of combat sports [29,30]. Moreover, left-handers appear to recruit brain networks differently for motor control compared to right-handers [31,32], which may further contribute to performance differences in certain sports [33].

While previous research has not provided *direct* evidence for either hypothesis—*NFDA* or *IS*—the former is generally favoured to explain the competitive edge associated with left-handedness in sports [1,13,14]. This preference is *indirectly* supported by data from *non*-antagonistic sports that do not involve any duel-like interactions, such as javelin throw, shot put, darts or tenpin bowling. Unlike some antagonistic sports showing a high incidence of left-handed athletes, non-antagonistic sports have been associated with left-hander proportions that align with those of the general population [13,34]. This has been interpreted as evidence against a frequency-independent left-handed superiority in sports, thereby challenging *IS* [13,14].

Although data from non-antagonistic sports have played a relevant role in the debate on *NFDA* and *IS*, studies in this area remain scarce and face methodological limitations:

(1) *Few studies:* Only a handful of studies have assessed the prevalence of left-handedness in non-antagonistic sports, such as track and field [13] and precision sports like darts and snooker [34].
(2) *Small sample sizes*: Some findings are based on very small samples. For instance, Raymond *et al*. [13] analysed just 22 female and 28 male athletes in javelin, discus and shot put, whereas Grouios *et al*. [12] reported data from only slightly larger discus-throwing samples (24 females, 27 males).
(3) *Limited generalizability*: Some studies rely on region-specific samples or short observation periods. For instance, Aggleton & Wood [34] analysed darts data exclusively from British athletes, while their tenpin bowling and snooker findings were based on a single competitive season (1987), limiting generalizability across geography and time. Notably, both geographical variation in human handedness [35] and temporal variation in left-hander frequencies have been observed in men's tennis [36] and baseball [37], suggesting that the prevalence of left-handedness in sport may change over time.
(4) *Male-dominated data*: For some sports, such as darts and snooker, data were sampled exclusively from male athletes, further narrowing the scope of findings.
(5) *Simplistic frequency analyses*: Previous studies in sports have largely relied on simple calculations of left-hander proportions within entire samples. This approach may obscure important nuances in the relationship between handedness and performance. Even if the overall prevalence of left-handers in a given athlete population aligns with general population estimates, left-handers could still be over- or under-represented at specific performance tiers. Without a more detailed analysis of left-handedness across different performance levels, it might be premature to conclude that handedness has no impact on athletic success [9].

Given these limitations, existing studies may not fully capture the role of handedness in non-antagonistic sports or accurately estimate left-hander frequencies among athletes. Expanding datasets and addressing previous methodological shortcomings provide a more robust empirical basis to assess the impact of handedness. To this end, we examined the prevalence of left-handedness among elite track-and-field athletes competing in the throwing events. These disciplines offer freely accessible and comprehensive online result archives, which allowed us to analyse year-end world rankings over a 20-year period (2005–2024). Our dataset comprises more than 6000 athletes—both female and male—and covers three non-antagonistic disciplines: javelin throw, discus throw and shot put. This approach addresses prior concerns about small sample sizes, gender imbalances, short observation periods and geographically restricted samples. Unlike prior studies, which relied on overall frequency calculations, we incorporated additional distributional analyses to examine whether left-hander frequencies vary across different performance levels. This approach allows a more refined assessment of whether handedness relates to athletic success. A uniform distribution of left-handers across performance tiers, with an overall prevalence near the general population (approx. 10%), would suggest that handedness is performance-irrelevant in non-antagonistic sports and would be consistent with the limited findings of previous research. By contrast, systematic over- or under-representation at specific performance levels—for instance, clustering at the top (figure 1B) or bottom (figure 1C)—would suggest that handedness is not performance-neutral but associated with differences in athletic performance, even when the overall proportion of left-handers in a discipline does not significantly diverge from general population estimates. Notably, an over-representation of left-handers at the top performance levels (figure 1B) would suggest an advantage in certain non-antagonistic athletic contexts. Such a finding would call into question the prevailing assumption that left-handers' benefits are confined to antagonistic sports and derive solely from frequency-dependent mechanisms, as posited by *NFDA*. Accordingly, we examined the prevalence of left-handedness among elite throwers and conducted exploratory analyses to assess whether left-hander proportions vary systematically by sport discipline, gender, performance level, across the observed time span (2005–2024) and geographic regions (defined by the country the athlete represents in competition). This expanded analytical framework enables us not only to test whether overall left-hander frequencies deviate from population expectations but also to investigate potential factors that may shape left-hander prevalence and that previous research could not examine due to methodological limitations.

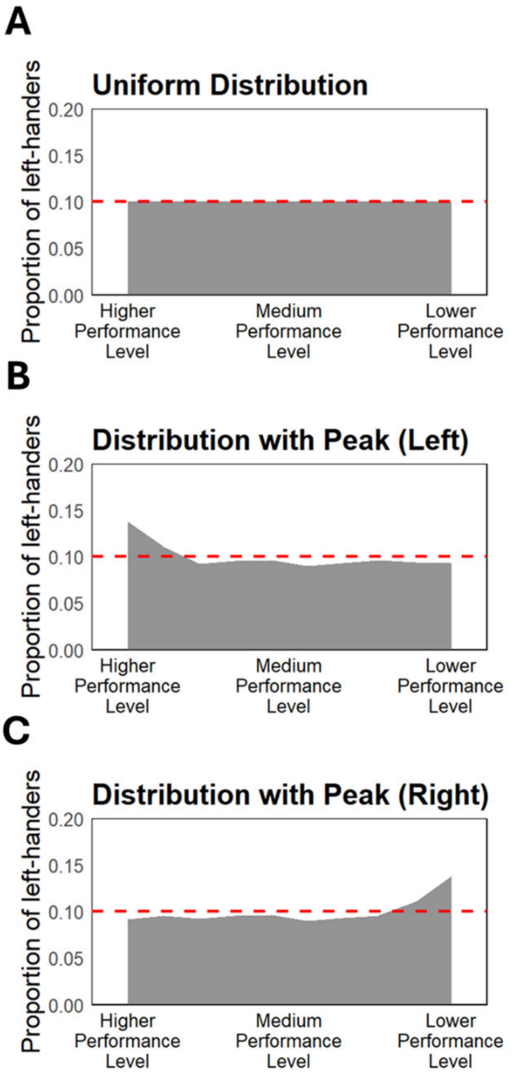

Figure 1. Examples of possible distributions of left-handed athletes. (A) Uniform distribution across performance levels, with an overall prevalence close to that of the general population (*ca* 10%). (B) Over-representation at higher and (C) over-representation at lower performance levels, despite an unchanged overall prevalence resembling general population estimates.

2. Material and methods

2.1. Data retrieval

Handedness data for elite athletes were gathered across three different sports disciplines: javelin throw, discus throw and shot put. For each discipline, lists of the top 300 senior female and male athletes with the greatest throwing distances, as recorded in the year-end world rankings, were manually retrieved from https://www.worldathletics.org for 20 seasons (2005–2024). Athletes' handedness was assessed by their functional, sport-specific hand use, i.e. the hand used for throwing or putting. This information was obtained from https://www.worldathletics.org or through additional Web searches, including photographs or videos showing the athlete in action (figure 2). The complete raw data are available in the electronic supplementary material.

2.2. Statistical analysis

All analyses were performed in R statistical software (v. 4.4.0; R Core Team, Vienna, Austria). For each sport and gender, all athletes were pooled across the study period (2005–2024) and ranked according to their best year-end position during this time. Based on these rankings, the overall proportion of

Figure 2. Right-handed athletes in action. Left: javelin thrower Johannes Vetter at the Speerwurfgala Pfungstadt (25 May 2017). Photo by Matthias Reiss, Wikimedia Commons, CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/). Centre: discus thrower Mélina Robert-Michon at the 2014 DécaNation (30 August 2014). Photo by Pierre-Yves Beaudouin, Wikimedia Commons, CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0/). Right: shot putter Yemisi Ogunleye at the Deutsche Hallenmeisterschaften (26 February 2022). Photo by Steffen Prößdorf, Wikimedia Commons, CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0/). All photos are unaltered.

left-handed athletes was calculated for each sport and gender across years. These aggregated proportions were then compared to the prevalence of left-handers in the general population (females: 9.5%; males: 11.6% [6]) using χ^2 goodness-of-fit tests. p-values were adjusted for multiple testing using the Benjamini–Hochberg procedure, and effect sizes were quantified with phi ($\varphi = \sqrt{(\chi^2/N)}$).

To extend the aggregated χ^2 analyses, we employed logistic regression models to test whether the prevalence of left-handedness varied systematically with various factors. The models were fitted using the *glm*() function from the *stats* package in R. The main model included *Sport* (javelin throw, discus throw, shot put), *Gender* (female, male), *Performance level*, *Geographical region* and *Year* (centred and standardized) as predictors. *Performance level* was categorized into rank groups in intervals of 50, based on athletes' highest position in the year-end world rankings between 2005 and 2024: ranks 1–50, 51–100, 101–150, and so on, up to 251–300. *Year* referred to the year in which each athlete achieved their best ranking position. *Geographical region* was related to athletes' country (Europe and Russia, Asia and Oceania, North America, Latin America and the Caribbean, Africa and the Middle East). Regions were defined to balance geographical coherence with sufficient sample sizes per group. This pragmatic grouping facilitates comparison of left-handedness prevalence across broad continental zones without implying genetic or cultural homogeneity. We then explored whether adding two-way interactions between variables (e.g. *Gender* × *Sport*, *Sport* × *Performance level*) improved model fit. These terms allowed us to test for potential moderating effects between key predictors while maintaining sufficient statistical power and interpretability. Higher-order interactions (three-way or more) were not included, as they would substantially increase model complexity and reduce interpretability without clear theoretical justification (i.e. specific *a priori* predictions). The linearity assumption for the continuous predictor *Year* was evaluated by fitting an exploratory model with restricted cubic splines (d.f. = 3) and comparing it to a linear-term model using a likelihood ratio test; this check ensured that the linear specification of *Year* was appropriate in the main analyses.

The overall contribution of each predictor to the final model was evaluated using omnibus likelihood ratio tests (type II), comparing models with and without the factor in question. Model results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). For the continuous predictor *Year*, ORs are expressed per 1 standard deviation (s.d.) increase in the predictor, indicating the factor by which the odds of left-handedness change for each 1-s.d. increase in that variable.

Model assumptions were checked by assessing multicollinearity (variance inflation factors) and the influence of individual observations (Cook's distance). Model performance was evaluated in terms of discrimination, quantified by the area under the receiver operating characteristic curve (AUC), and calibration, using the Hosmer–Lemeshow goodness-of-fit test.

As a sensitivity analysis, we additionally fitted a generalized linear mixed-effects model (GLMM) with a random intercept for *Country* using the *glmer*() function from the *lme4* package in R. This model allowed us to account for potential clustering of athletes within countries. We compared the GLMM with the standard GLM in terms of model fit (AIC), the estimated variance of the random effect, and the stability of fixed-effect estimates (ORs and 95% CIs).

3. Results

Between 2005 and 2024, the top 300 year-end rankings for javelin throw, discus throw and shot put included 9645 individual athletes, of whom the throwing hand could be determined for 6339 (3091 females and 3248 males). Overall, the proportion of left-handers was significantly lower compared to general population estimates across disciplines and for both female and male athletes (all $p \leq 0.001$, all $\varphi \geq 0.21$; table 1).

The final logistic regression model (GLM) included *Sport* (javelin throw, discus throw, shot put), *Gender* (female, male), *Year* (standardized), *Performance level* (ranking groups of 50) and *Geographical region* as predictors. For *Geographical region*, Africa and the Middle East were excluded due to small sample sizes (electronic supplementary material, table S1). A nonlinearity check for *Year* using a restricted cubic spline (d.f. = 3) revealed no improvement in model fit compared to the linear term (likelihood ratio test: $\chi^2(2) = 0.47$, $p = 0.790$), supporting the appropriateness of the linear specification. Two-way interactions between predictors were explored but did not improve model fit and were therefore not included in the main analysis. Likelihood ratio tests indicated that none of the tested interactions reached statistical significance (all BH-adjusted $p \geq 0.39$). Model fit indices were also not improved, with AIC values comparable to or higher than those of the main-effects model. We therefore retained the simpler main-effects model for all subsequent analyses.

Omnibus likelihood ratio tests revealed a significant effect of *Gender* on the odds of left-handedness ($\chi^2(1) = 10.96$, $p = 0.001$), with male athletes showing higher odds than females (OR = 1.63, 95% CI 1.21–2.18, $p = 0.001$) (figure 3). *Sport* showed a trend towards an overall effect ($\chi^2(2) = 5.09$, $p = 0.079$), with *post hoc* pairwise comparisons indicating that javelin throwers had lower odds of left-handedness compared to shot putters (OR = 0.66, 95% CI 0.45–0.96, BH-adjusted $p = 0.088$); other contrasts were non-significant: discus versus javelin (OR = 1.22, 95% CI 0.82–1.81, BH-adjusted $p = 0.321$) and discus versus shot put (OR = 0.80, 95% CI 0.58–1.11, BH-adjusted $p = 0.280$) (figure 3). *Year* did not show an overall effect ($\chi^2(1) = 0.31$, $p = 0.581$; OR per 1 s.d. increase = 1.04, 95% CI 0.90–1.20), suggesting there was no evidence for temporal variation in left-hander prevalence across the study period. Similarly, no overall effects were found for *Performance level* ($\chi^2(5) = 2.95$, $p = 0.707$) and *Geographical region* ($\chi^2(3) = 3.81$, $p = 0.282$); *post hoc* pairwise comparisons yielded ORs between 0.69 and 1.29 for *Performance level* (all 95% CIs included 1; all BH-adjusted $p \geq 0.848$; figure 3) and 0.61 and 1.53 for *Geographical region* (all 95% CIs included 1; all BH-adjusted $p \geq 0.252$). The lack of variation in left-hander proportions across performance levels indicates a uniform distribution of left-handedness as depicted in figure 1A.

Model diagnostics indicated no evidence of problematic multicollinearity (all $\text{GVIF}^{(1/2\text{d.f.})} \leq 1.02$), and 199 observations (3.3%) exceeded the Cook's distance threshold ($4/n$); these were retained as the model converged and results were stable. Model performance metrics were as follows: AUC = 0.601; Hosmer–Lemeshow goodness-of-fit test: $\chi^2(8) = 18.002$, $p = 0.021$.

A GLMM including a random intercept for *Country* was fitted as a sensitivity analysis to account for potential clustering. The estimated random-effect variance was modest ($\sigma^2 = 0.39$, s.d. = 0.63), indicating some between-country heterogeneity. Model fit was slightly improved compared to the simpler GLM (AIC = 1746.3 versus 1753.0). Fixed-effect estimates were highly similar across both models, and substantive conclusions regarding *Gender*, *Sport*, *Year*, *Performance level* and *Geographical region* remained unchanged. The GLMM exhibited convergence warnings and nearly unidentifiable parameters, suggesting limited numerical stability. Therefore, the simpler GLM was retained as the primary model.

4. Discussion

Compared to antagonistic sports, the role of left-handedness in non-antagonistic sports has received considerably less research attention. To address this gap, this study presents the first large-scale investigation of handedness in track-and-field disciplines. Specifically, we analysed the prevalence of left-handed athletes in elite javelin throw, discus throw and shot put over a 20year period (2005–2024).

Across disciplines and in both female and male athletes, the frequency of left-handedness was significantly lower than expected based on general population estimates. The proportion of left-handed athletes differed by gender, with men showing a higher prevalence than women. This is consistent with gender differences in the general population [6]: both among track and field athletes and in the overall population, approximately 1–2% more males are left-handed than females. Left-handedness also tended to be more common in the shot put than in the javelin. No significant effects

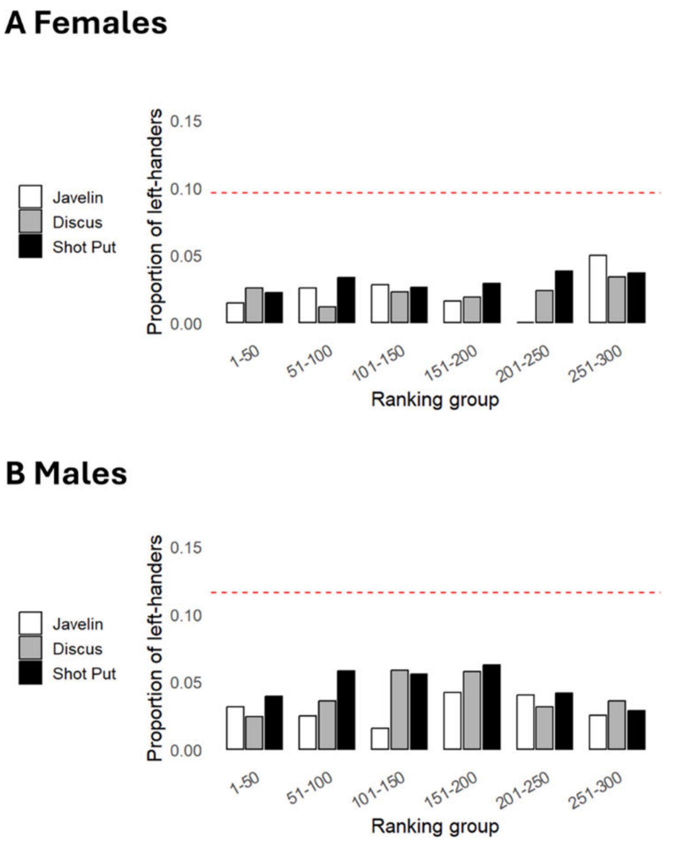

Figure 3. Prevalence of left-handed female (A) and male (B) athletes across ranking groups using ranking intervals of 50. The overall proportion of left-handers in the general population is indicated by the red dashed line (females: 9.5%; males: 11.6% [6]).

Table 1. Absolute and relative frequencies of left-handed athletes and results from χ^2 goodness-of-fit tests comparing left-hander frequencies among athletes with those in the general population (9.5% and11.6%, respectively [6]). NA, data not available.

gender	sport		handedness						
		N	left	right	NA	% left	χ^2	p	φ
female	javelin throw	894	18	876	599	2.01	58.282	<0.001	0.26
	discus throw	1051	23	1028	554	2.19	65.352	<0.001	0.25
	shot put	1146	35	1111	597	3.05	55.383	<0.001	0.22
male	javelin throw	955	28	927	616	2.93	69.974	<0.001	0.27
	discus throw	1091	42	1049	511	3.85	63.908	<0.001	0.24
	shot put	1202	57	1145	429	4.74	55.129	<0.001	0.21

were found for performance level, changes over time during the study period, or geographical region (e.g. Europe and Russia, North America, etc.).

4.1. Why are left-handers under-represented in throwing sports?

Our findings are purely descriptive and, as such, do not permit definitive conclusions regarding the mechanisms underlying the pronounced under-representation of left-handers in throwing disciplines. Nonetheless, we outline below several potential explanatory pathways that warrant systematic examination in future research.

4.1.1. Potential socio-cultural factors

The low proportion of left-handed athletes in track-and-field throwing disciplines may be influenced by socio-cultural factors, such as bias and lack of experience in coaching and talent scouting. Given the technical complexity of javelin, discus and shot put [38,39], coaches—most of whom are likely right-handed—may perceive left-handed movements as less familiar or even 'unnatural'. This could create subtle, cumulative disadvantages, particularly at the youth level: talented left-handed junior athletes may receive less individualized instruction, either because their talent is underestimated or because trainers lack the experience to fully support left-handed development. Such limitations are likely to be most pronounced in local or regional clubs, where athletes typically begin their track-and-field careers. In these settings, promising left-handers may be overlooked and fail to advance into higher-level squads, where professional coaching structures and greater expertise are available. As a result, left-handed athletes may have fewer opportunities to train under optimal conditions and less confidence in their technique, ultimately reducing their chances of progressing to elite levels. Suboptimal training conditions for left-handers have also been discussed in other contexts. For instance, in surgical training, being left-handed has historically been regarded as disadvantageous [40]. While right-handed surgeons report greater difficulty and less comfort when teaching left-handed trainees, the challenges faced by left-handed surgical trainees stem primarily from barriers in training rather than from any inherent difference in ability [41].

One might argue that the disadvantages left-handed athletes face due to unfamiliarity with left-handed technique and coaching biases in throwing events should likewise occur in other technically demanding sports, such as combat sports or interactive ball games. However, in many interactive sports, left-handers are actually over-represented and often enjoy a competitive advantage (e.g. [7,9,14]). In fencing, for instance, left-handedness has been recognized as advantageous for centuries [42], potentially fostering preferential treatment rather than disadvantage. In these contexts, coaches may actively value left-handed athletes and be motivated to develop specialized training strategies for them. By contrast, in track-and-field throwing events, left-handedness has not been discussed as either advantageous or disadvantageous, neither in the academic literature [13] nor in broader sports discourse. In such settings, left-handers' rarity and unfamiliar movement patterns could create disadvantages, rather than advantages. This contrast suggests that potential biases in coaching and selection may operate differently across sports and highlights the need for systematic investigation of whether left-handed athletes in track and field are subject to subtle disadvantages in talent identification and development [43].

The under-representation of left-handers in non-antagonistic sports may also be linked to early sport specialization and the competitive advantages left-handers can have in certain antagonistic disciplines. It is plausible that left-handed individuals who pursue competitive sports—due to personal interest, familial or socio-cultural encouragement, or personality traits—are more likely to gravitate towards antagonistic sports, where they may benefit from a performance edge. A similar idea has been proposed by Lawler & Lawler [44], who speculate that the below 10% proportion of left-handers they observed in basketball may, in part, result from talented left-handed athletes being steered towards baseball, where they enjoy a clearer competitive advantage. Such a bias in early sport choices could contribute to the under-representation of left-handers in non-antagonistic disciplines from the outset. If left-handedness provides no direct performance advantage in these sports, this initial imbalance may persist across higher performance levels. Once such biases in sport choice begin to emerge, recruitment and talent-identification processes may further amplify them. Coaches and scouts in sports where left-handers are known to hold an advantage (e.g. baseball, fencing or certain racket sports) or where they are needed due to positional demands (e.g. handball or water polo [45]) may preferentially recruit, invest in or retain young left-handed athletes, thereby reinforcing their over-representation. Conversely, in disciplines where handedness provides no clear benefit, left-handers may be less actively sought or may even encounter subtle discouragement due to predominantly right-oriented technical set-ups and coaching practices. Over time, this interplay of self-selection, differential encouragement and sport-specific recruitment strategies could generate systematic imbalances in the distribution of left-handers across sporting domains. When the overall proportion of left-handers among athletes remains close to population-level estimates, their over-representation in some antagonistic sports must necessarily coincide with under-representation in others.

Further social factors may contribute to the under-representation of left-handers in elite throwing sports. Until the 1970s, many left-handers were taught to write with their non-dominant right hand [1], typically during preschool or early elementary school years. A similar socio-cultural pressure may have existed in past decades within professional sports environments, where young track-and-field athletes might have been systematically discouraged from throwing left-handed and instead trained to throw right-handed. If such a socio-cultural 'conversion effect' was particularly prevalent in earlier decades—similar to handwriting in schools—one would expect athletes born in the 1970s, who were still active in the 2000s, to exhibit a lower prevalence of left-handed throwers compared to later cohorts. Although our dataset does not include athletes' year of birth, we explored potential temporal dynamics as a proxy. Specifically, our dataset provides information about individual athletes' highest position in the year-end rankings from 2005 to 2024. Given that throwers typically reach their peak performance between their mid-twenties and around 30 years of age [46,47], those who achieved top rankings in the mid to late 2000s were likely born in the mid to late 1970s. However, we did not observe any fluctuation in left-hander prevalence across the investigated 20year period (2005–2024), thereby raising doubts about a socio-cultural 'conversion effect' as an explanation for the under-representation of left-handers in throwing sports.

4.1.2. Potential biomechanical differences between left- and right-handed throwing

The striking under-representation of left-handed javelin throwers, discus throwers and shot putters raises the question of whether left-handedness may be linked to inherent challenges in elite throwing sports. One possible explanation involves biomechanical differences between left- and right-handed athletes. Throwing events such as javelin, discus and shot put require athletes to generate peak acceleration and release velocity within a very brief delivery phase. Research in professional baseball has identified kinematic and kinetic differences between left- and right-handed pitchers: right-handers, for instance, exhibit greater trunk–shoulder separation at front-foot contact, larger maximal shoulder external rotation and a more closed lead-foot position [48,49]. These parameters are associated with more efficient kinetic-chain transfer and higher release velocity, and a recent study found that right-handed baseball pitchers threw slightly harder than left-handed pitchers (average velocity: 127.02 versus 125.45 $km\,h^{-1}$) [50]. Possibly, analogous disparities might also be present in track-and-field throwing events. For instance, comparable mechanics underlie acceleration in javelin throwing, where hip–shoulder separation, shoulder external rotation and front-leg blocking are key determinants of release speed [51] (figure 4). Given these mechanical parallels, lateralized differences observed in pitching could plausibly extend to track-and-field throwing events. Whether such biomechanical asymmetries translate into meaningful performance disadvantages remains unclear, especially as our data revealed no association between handedness and performance tier. Notably, no study to date has directly examined biomechanical disparities between left- and right-handed throwers in athletics, underscoring an important direction for future research.

4.1.3. Are there left-handers who throw right-handed?

Most previous studies on handedness in sports have classified athletes' handedness based on their sport-specific functional hand use—e.g. which hand is preferentially used to hold the racket or one-handed weapon (e.g. [7–9]). Similarly, in the present study, handedness among track-and field athletes was operationalized based on their throwing or putting hand. In unimanual sports, such as the throwing events, the functional hand used for performance is usually assumed to align with an athlete's general, everyday hand preference. Supporting this assumption, Loffing *et al*. [10] reported strong correlations between individuals' preferred hand for unimanual sport-specific actions (e.g. holding a racket, fencing or throwing objects) and their scores on the EHI [2]—a standardized questionnaire widely used to assess general handedness. The EHI typically includes 10 or more items, asking participants which hand they prefer for a range of everyday activities such as writing, drawing or tooth brushing. EHI scores range from –100 (consistent left-hand preference across all tasks) to +100 (consistent right-hand preference), allowing classification into handedness categories of varying granularity [1], e.g. a two-way classification (left- versus right-handers), a three-way classification (left-handers, ambidextrous, right-handers) or a five-way classification (strong left-hander, weak left-hander, ambidextrous, weak right-hander, strong right-hander).

Although Loffing *et al*. [10] reported high correlations, these were not perfect. This means that some individuals classified as left- or right-handed according to their EHI score may nonetheless perform certain unimanual sport-related actions, such as throwing, with the opposite hand. Interestingly, Loffing *et al.*'s data suggest that this 'imperfect' correspondence was mainly driven by participants classified as left-handed. Specifically, when dividing their sample into left- and right-handers based on EHI scores (left-handers: $-100 \geq EHI < 0$; right-handers: $0 < EHI \leq +100$), 19% of those identified as left-handed preferred to throw with their right hand, whereas only 0.9% of right-handers preferred to throw with their left hand. This pattern is consistent with earlier large-scale findings reporting that up

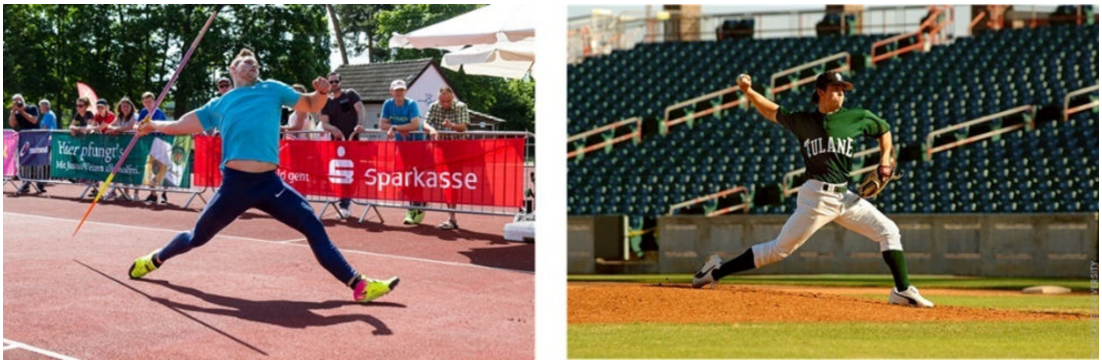

Figure 4. Similar biomechanics between javelin throw and pitching in baseball. Left: javelin thrower Johannes Vetter at the Speerwurfgala Pfungstadt (25 May 2017). Photo by Matthias Reiss, Wikimedia Commons, CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/). Right: a male baseball pitcher (3 February 2006). Photo by Tulane Public Relations, Wikimedia Commons, CC BY 2.0 (https://creativecommons.org/licenses/by-sa/2.0/). All photos are unaltered.

to a third of individuals who used their left hand for writing preferentially threw with their right hand, whereas only 1–2% of right-hand writers showed inconsistent hand use for throwing [52,53].

Estimates of general hand preference in the overall population are typically based either on multiple item questionnaires like the EHI or on individuals' preferred hand for specific everyday tasks such as writing [6]. Thus, it is possible that the proportion of left-throwing athletes observed in our track-and-field sample may appear lower than population-level estimates of left-handedness, simply because a non-trivial proportion of individuals who would be classified as left-handed based on EHI scores or single-task preferences may nonetheless throw with their right hand. This aligns with the general observation that those classified as left-handers, according to established tests such as EHI, exhibit weaker and more variable patterns of lateralization than right-handers: relatively more left-handers display less consistent hand preference across tasks, whereas right-handers tend to show stronger and more uniform right-hand preference [1,54,55].

However, while such inconsistencies between general and sport-specific hand preference may contribute to the low proportions of left-throwing athletes observed in elite throwing events, they cannot fully account for our findings. Assuming that the prevalence of left-handedness as assessed by standardized tests is approximately 10% in the general population, and that around 20–30% of such classified left-handers throw preferentially with their right hand, while only a very small fraction of right-handers throw with their left, one would still expect at least about 7–8% of individuals to throw left-handed. This expected proportion is still higher than the approximately 2–5% observed in our sample of elite track-and-field athletes, suggesting that additional factors likely contribute to the marked under-representation of left-handers in these disciplines.

4.1.4. Predictive motor control and hemispheric brain specialization

Individuals classified as left-handed based on the EHI or other standardized assessments differ from right-handers not only behaviourally—showing greater variability and less consistency in hand preference across tasks—but also in the neurobiological organization of motor control. Left-handers tend to exhibit weaker or less consistent hemispheric asymmetries during unimanual actions, particularly in tasks that rely on *predictive motor control*—i.e. the ability to generate precisely timed and internally guided movement sequences. For example, during finger-tapping [56], sequential finger movements [57], pantomiming familiar object manipulations [58] or rapid, targeted mouse movements [32], left-handers show, on average, more bilateral hemispheric activation than right-handers, who typically display stronger left-hemisphere dominance.

These findings can be interpreted within the framework of the dynamic dominance model (DDM), which proposes that upper-limb and hand use rely on two distinct yet complementary modes of motor control [59–61]. According to this model, the hemisphere contralateral to the dominant hand (the left hemisphere in right-handers) is specialized for *predictive control* of limb and task dynamics, optimizing movement trajectories for speed, power and efficiency. In contrast, the ipsilateral hemisphere (the right hemisphere in right-handers) is specialized for *impedance control*, stabilizing performance and reducing variability under changing mechanical conditions. While the DDM has been developed primarily from studies involving individuals who reach typical right-handed scores on standardized handedness inventories, its applicability to left-handers remains less well explored [33] (but see [62]). However, if left-handers indeed exhibit more bilateral hemispheric recruitment during tasks requiring predictive control, this could indicate less lateralized and less specialized predictive mechanisms. In elite throwing sports such as javelin, discus and shot put, predictive control is crucial: athletes must produce highly coordinated, high-power movement sequences with precise timing. A less strongly lateralized and specialized neural organization might therefore reduce the efficiency or robustness of these finely tuned predictive processes.

An alternative interpretation of the functional role of bilateral recruitment is that left-handers do not necessarily exhibit *less* lateralized or specialized predictive motor control, but instead may simultaneously recruit both contralateral networks specialized for predictive control and ipsilateral networks specialized for impedance control [33]. Since elite throwing events primarily depend on predictive control of the throwing arm, with relatively little demand for impedance control, the concurrent activation of networks with differing functional specializations could introduce interference or reduce motor efficiency—potentially contributing to performance disadvantages in left-handed throwers.

5. Limitations and future directions

The overall fit of our GLM was modest, as indicated by the low AUC and the Hosmer–Lemeshow test. However, this limitation is likely not methodological, but conceptual: apart from gender, other variables exerted only limited influence. Accordingly, the predictors considered here were not expected to yield high predictive power.

The footage used to determine athletes' throwing hand was obtained from official or reputable sources (e.g. World Athletics, national athletics federations, international competition broadcasts or established sports media). We did not alter any images or videos, and only footage clearly showing the athlete's throwing action was included. Nevertheless, we cannot fully exclude the possibility that some online materials were horizontally flipped prior to publication on third-party websites, potentially introducing classification errors. To minimize this risk, handedness classification was cross-checked across multiple independent sources (e.g. several photographs or videos per athlete whenever available). In cases of any ambiguity, athletes were excluded from the dataset.

Both previous research and the present study have operationalized athletes' handedness based on the hand preferentially used to perform sport-specific unimanual actions. Although correlations between lateral preferences in sport-specific, one-handed actions and general hand preference in everyday manual activities—as typically measured by instruments such as the EHI—are generally strong, some individuals display inconsistent hand preferences across different tasks. In particular, a notable proportion of individuals classified as left-handed according to standardized handedness assessments nevertheless show a preference for their right hand in specific contexts. Consequently, studies investigating the role of handedness in sports performance that rely solely on sport-specific hand preference may classify some athletes as right-handed, even though they predominantly prefer their left hand in most other domains. The comprehensive assessment of handedness may also enable the empirical testing of a recent philosophical perspective of handedness, which argues that throwing is a right-handed movement (in a right-handed world) which puts left-handed throwing at a disadvantage [63].

Collecting data on both sport-specific hand preference and general handedness via standardized inventories would therefore provide a more comprehensive understanding of the relationship between handedness and athletic performance. Such combined measures would not only allow researchers to test whether sport-specific hand preference itself is related to athletic success but also to examine whether the *degree* of lateralization—i.e. the consistency or strength of hand preference across different contexts—plays a role. This approach could help to reveal whether athletes with more consistent, cross-task hand preferences differ systematically from those with more variable or context-dependent preferences, thereby offering deeper insight into the mechanisms linking handedness and performance in sport.

This study provides the first large-scale dataset on sport-specific hand preference in elite track-and-field throwing events as an example of non-antagonistic sports. Contrary to the prevailing assumption that handedness plays a role in antagonistic, such as combat sports and interactive ball games, but not non-antagonistic sports (e.g. [7,8,13]), we found that left-handed throwers appear to be under-represented and possibly disadvantaged in these events. To further elucidate the relationship between hand preference and athletic performance in non-antagonistic sports, future studies should examine additional disciplines of this kind (e.g. darts, bowling, curling, shooting, etc.).

6. Conclusion

In elite track-and-field throwing events (javelin, discus and shot put), the proportion of left-throwing athletes was substantially lower than the approximately 10% prevalence of left-handers in the general population. This under-representation may reflect disadvantages faced by left-handed athletes in throwing sports, potentially arising from a range of socio-cultural and non-social influences, or a combination of both. Previous research has typically assumed that left-handedness confers a performance advantage in antagonistic, duel-based sports, while being largely irrelevant in non-antagonistic disciplines. By contrast, our findings suggest that left-hand preference may also be associated with disadvantages in non-interactive sports. The mechanisms discussed here as potential explanations for this pattern could inform future research on the origins and implications of handedness differences in athletic performance.

Ethics. This work did not require ethical approval from a human subject or animal welfare committee.

Data accessibility. The data supporting this article have been uploaded as part of the electronic supplementary material [64].

Declaration of AI use. We have not used AI-assisted technologies in creating this article.

Authors' contributions. T.S.: conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing—original draft; F.L.: conceptualization, writing—review and editing; E.F.: conceptualization, funding acquisition, writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

Funding. This work was supported by the Italian Ministry of University and Research (MUR) and the European Union within the programme PRIN 2022 awarded to E.F. (PRIN 2022 (DD 104 of 02/02/22) PNRR-M4-C2-INV 1.1-PRIN project title [Laterality distribution across the two sexes (LADISEX): comparative data for theoretical models], project identification code [202222EJZE]—CUP [E53D23008620001]—UNITN Fund [40104476-FRASNELLI PRIN 2022] funded by the European Union Next Generation EU).

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