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Research article

Relative Age Effect Among World-Class Jump Athletes

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Abstract

The relative age effect (RAE), as a widely recognized phenomenon in the field of sports, reveals the bias in talent selection across various sporting disciplines and the neglect of certain potentially gifted athletes. The study aims to analyze RAE incidence and athletic performance among the top 100 world-ranked high jump and long jump athletes, as well as to examine the differences across the five continents. Finally, successful professional athletes are divided into two groups, namely the "All-Phase Success (AS)" and the "Senior Success (SS)" based on their success during their youth. A comparison is made between the performance and age differences of these two groups. The results indicate: 1) the RAE is present across all age groups (U18, U20, Senior) and both sexes in the high jump and long jump events (except for the senior male high jump). 2) Athletes in the AS group are consistently 2 - 3 years younger at each key stage of their athletic careers compared to those in the SS group. 3) Relatively younger athletes exhibit higher transition rates during their youth period compared to relatively older athletes. However, despite the larger number of relatively older athletes, AS athletes still outperform SS athletes in high jump and long jump events.

Key words: Relative age effect, jump, performance, transition rate.

Introduction

"Relative age" refers to the age difference between individuals grouped together for a particular activity (Barnsley et al., 1985). The immediate and long-term effects of these differences among individuals are termed the "Relative Age Effect", abbreviated as "RAE" (Cobley et al., 2009). With continued research into the RAE, researches consistently shows that the presence and impact of RAE are widespread across sports. Cobley et al. (2009) and Smith et al. (2018), among others, conducted meta-analyses on the prevalence and magnitude of RAE in sports, considering factors such as gender, age, competitive level, skill level, and sports discipline. The results outline the basic understanding of RAE in sports: females tend to have slightly lower RAE values than males; there is a generally higher risk of RAE before adulthood, with the risk gradually decreasing or becoming insignificant after adulthood; the popularity and competitiveness of a sport are positively correlated with the risk of RAE; and sports with higher skill requirements are associated with lower RAE risks. Track and field as a widely practiced sport with numerous events worldwide, continues to be the subject of research confirming the basic RAE patterns observed in other sports domains (Raschner et al., 2012; Romann and Cobley, 2015; Albuquerque et al., 2015; Brazo-Sayavera et al., 2016; 2018; Kearney et al., 2018; Brustio et al., 2019; 2024b; Bezuglov et al., 2024).

Multiple hypotheses have been proposed to explain the RAE (Musch and Grondin, 2001; Hancock et al., 2013), but the one most supported is the "maturation selection hypothesis" (Cobley et al., 2009). Just as in most sports, higher stature, body weight (to some extent), aerobic capacity, muscle strength, endurance, and speed provide performance advantages (Malina et al., 2007). Both the high jump and long jump events primarily rely on the combination of running and jumping techniques, but the technical execution in the high jump is more complex (Boccia et al., 2017). In terms of running and jumping abilities, boys experience accelerated growth from ages 12 to 13 (running) or 14 (jumping), with the growth rate slowing down by age 18. In contrast, girls show a gradual decline in growth rate from age 12, reaching a plateau around age 16 (Tønnessen et al., 2015). From age 14 onwards, boys outperform (countermovement jump and squat jump) girls in jumping due to longer legs and greater leg muscle mass (Temfemo et al., 2009). And Boccia et al., (2017) demonstrated that high jump and long jump performances progress to a similar degree to jumping abilities measured with typical field tests like counter movement jumps. The period of rapid growth in jumping ability during adolescence is also the stage with the highest prevalence of the RAE (Cobley et al., 2009).

Coaches, as the primary selectors, tend to equate physical advantages with athletic talent (Furley and Memmert, 2015). Additionally, to achieve better results, they actively favor athletes with "maturity advantages" (Hancock et al., 2013). Therefore, due to early physiological advantages, athletes who are relatively older and develop earlier have a greater advantage in selection, thus increasing their chances of being chosen (Lovell et al., 2015). However, among the selected athletes, while the RAE is generally present, only a few younger athletes (U12, U14) show significant differences in physical abilities (Lovell et al., 2015). Most athletes do not exhibit differences in physical abilities (Hirose, 2009; Deprez et al., 2013; Ulbricht et al., 2015). Social factors such as coaches, parents, and athletes themselves exacerbate the occurrence of the RAE (Hancock et al., 2013). Wattie et al. (2015) suggested that environmental constraints affecting RAE include broader social structures, such as the physical environment, sociocultural factors (sport popularity, competition level), policies, and the influence of key figures in the athlete's life.

In terms of athletic performance, the studies demonstrated that the risk of RAE among world-class track and field athletes decreases with age and as the level of competition rises. While RAE is significantly present across various events at the U18 and U20 stages, its incidence notably declines in the senior category (Brustio et al., 2019;

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Bezuglovet al., 2024). However, within the same events and age groups, the level of RAE increases as athletic performance improves (i.e., from the top 25% to the top 10%) (Brustio et al., 2024a).

In exploring the reasons for the significant decline in RAE from adolescence to the professional stage, it was found that in youth sports such as basketball (Arrieta et al., 2016; Ibáñez et al., 2018), soccer (González-Víllora et al., 2015), skiing (Fumarco et al., 2017), and the 60-meter sprint (Romann and Cobley, 2015), RAE has been shown to be linked to athletic performance. Relatively older athletes tend to perform better, and their teams also achieve superior results. However, relatively younger athletes typically transition to higher-level competitions at a greater rate than their older counterparts (Cobley et al., 2009). This phenomenon is referred to as "reversal of advantage" (McCarthy and Collins, 2014) or "Underdog effect" (Gibbs et al., 2012).

Multiple studies have confirmed that relatively younger athletes in football are more likely to be selected by professional teams and reach elite levels (Coutts et al., 2014; Boccia et al., 2017; 2023; Brustio et al., 2023b). Research by Brustio et al. (2023a) on the transition rates of athletes in sprinting and jumping events from junior to professional competitions indicates that relatively younger athletes demonstrated higher transition rates compared to relatively older athletes. Additionally, there are intercontinental differences in transition rates. The phenomenon of 'advantage reversal' also appears in sports like rugby (McCarthy and Collins, 2014), cricket (McCarthy et al., 2016), and ice hockey (Gibbs et al., 2012).

The cause of this phenomenon may be the increased injury rates among relatively older athletes (Vaeyens et al., 2005; Wattie et al., 2007). It could also be attributed to relatively younger athletes overcoming the physical disadvantage posed by the relative age difference in the early stages of their athletic development, benefiting from it in competition. Gibbs et al., (2012) and others refer to this phenomenon as the "Underdog effect," where younger athletes initially perceived as disadvantaged due to their relative age ultimately gain an advantage as the physical development gap narrows with age. Additionally, athletes' ability to endure adversity and excel in high-level challenges during their developmental stages is considered a precursor to "success" across various sports (McCarthy et al., 2016).

In recent years, there has been increasing evidence indicating that success in youth athletics does not necessarily guarantee success throughout an athlete's entire career (Boccia et al., 2021a; 2021b; Brustio et al., 2019; 2024b). For instance, Boccia et al. (2021a) analyzed the performance differences and mutual occupation ratios between the top 50 youth (U18) and professional jump athletes worldwide. Results showed low transition rates from youth to professional levels: 8% for males and 16% for females. Moreover, the proportion of professional athletes who ranked in the top 50 in youth competitions was also low (8% for males, 16% for females). In terms of performance, professional athletes significantly outperformed their younger counterparts as age increased.

Boccia et al (2017) conducted a rank of the top 200 high jump and long jump athletes in Italy from 1994 to 2014. Results indicated that only 10-25% of adult top-level athletes reached elite performance levels at the age of 16. Among the top young athletes at 16 years old, approximately 60% did not maintain the same level of performance in adulthood. Boccia et al (2017) argued that early specialization does not provide a significant advantage for long-term success, as the proportion of athletes who succeed in youth and continue to do so in adulthood is very low. However, whether the success gained from early specialization provides an advantage for athletes who have already achieved success in their professional careers remains a topic worthy of further investigation.

In this research context, the main objective of this study is to analyze the differences in RAE prevalence among world-class high jump and long jump athletes across events, gender, and regions (continents), and its relationship with athletic performance. Additionally, the study further explores the issue of transition rates. It examines whether the early athletic performance of successful senior athletes was also successful, and analyzes the differences in RAE incidence and performance between athletes in the AS group and the SS group.

Methods

Participants

This study selected male and female athletes who ranked in the top 100 of the World Athletics Federation (formerly known as the International Association of Athletics Federations, IAAF) annual best performances in the high jump and long jump events from 2013 to 2022, and/or athletes who participated in the World U18 and U20 events from 2010 to 2019 and ranked in the top 100. Performance records must meet wind speed requirements, and athletes who have been disqualified for doping violations will be excluded. Athletes must have at least two valid performance records in each of the U18, U20, and senior categories to be included in the study. Table 1 describes the proportion of athletes meeting the selection criteria compared to the total number of athletes in each group. The study was approved by the local institutional ethics committee.

Table 1. The number of eligible athletes in the U18, U20, and senior categories (2010-2022).

Age Group	Man Long Jump		Man High Jump		Women Long Jump		Women High Jump	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*
U18（TOP100）	129	15.67	132	15.68	202	27.67	213	30.34
U20（TOP100）	190	25.78	233	34.84	227	35.45	256	44.83
Senior（TOP20）	45	48.91	58	62.37	42	49.41	45	58.44
Senior（TOP50）	116	47.54	118	61.78	112	55.45	114	61.96
Senior（TOP100）	222	53.37	215	67.19	208	56.22	206	59.89

Relative Age Effect (RAE)

According to the World Athletics age grouping cutoff date standard, athletes' birth dates are divided into four quarterly groups, namely Q1, Q2, Q3, and Q4: January to March is Q1; April to June is Q2; July to September is Q3; October to December is Q4. Since the athletes are sourced globally, the default assumption is that the distribution of athletes across the four quarters is evenly spread (25% for each quarter). The RAE value is determined based on the ratio of Q1/Q4 (Formula 1) and 95% confidence intervals [95% CIs] (Boccia et al., 2021a; Brustio et al., 2019). A relevant RAE was assumed if the confidence interval of the OR did not include 1 (Romann et al., 2018).

$$OR = \frac{Number\ of\ athletes\ born\ in\ Q_1}{Number\ of\ athletes\ born\ in\ Q_4} \quad (1)$$

The *OR* for the Q1 vs Q4 comparison was interpreted as follows: $OR < 1.22$, $1.22 \leq OR < 1.86$, $1.86 \leq OR < 3.00$, and $OR \geq 3.00$, indicating negligible, small, medium and large effects, respectively (Olivier and Bell, 2013). The transition rate (TR) in this study refers to the proportion of athletes successfully transitioning from youth to professional careers, as indicated by Formula 2 (Brustio et al, 2023a).

$$TR = \frac{The\ number\ of\ U18\ or\ U20\ athletes\ transitioning\ to\ the\ top\ 100\ in\ the\ adult\ group}{The\ number\ of\ athletes\ in\ the\ top\ 100\ of\ the\ adult\ group} \quad (2)$$

Data collection and processing

The athlete data for this study is sourced from the official website of World Athletics (https://www.iaaf.org/home). It includes the birthdates and countries/regions of all athletes across all categories. For professional athletes, the data includes their age at the time of their first entry into the database, their performance records (the first recorded performance on the international track and field website), the age and performance when they first achieved the professional performance standard (the 10-year minimum performance average for the professional category), their personal best performance and age when achieved, and the average of their top 10 performances in individual events.

First, a descriptive analysis was conducted on the number of athletes in the top 100 for each event (U18, U20, Senior), as well as their best performances (using their career-best performances within the group as of December 12, 2023). As the data in the study were not normally distributed, a non-parametric test (Kruskal-Wallis) was used to examine regional differences in athletic performance. In addition, regions with less than 10 athletes were excluded from the analysis. For groups with significant regional differences, post-hoc pairwise comparisons were conducted to identify which continents had performance differences. Second, RAE values for each group were calculated, and the Kruskal-Wallis test was used to evaluate whether RAE had any impact on performance across the quartiles.

Whether different ranking thresholds for senior athletes (top 100, top 50, top 20) are screened based on having at least two valid scores in the youth stage (U18 and/or U20), with athletes meeting the criteria defined as “All-Phase Success (AS)” athletes and those not meeting the criteria defined as “Senior Success (SS)” athletes. These two types of athletes will be categorized into AS and SS groups, respectively, and RAE values will be calculated for both groups. At the same time, based on seven key data points including the age and score at the first entry into the database, age and score when first qualifying for the professional group, personal best score and age, and the average of personal top 10 scores, an independent sample T-test will be used to analyze the differences between the two groups.

All data are analyzed with SPSS 29.0 (SPSS Inc., Chicago, IL, USA). The graphs were prepared with GraphPad Prism 10 (San Diego, CA, USA) and Hiplot (www.hiplot.com.cn).

Results

The number of athletes in the top 100, their scores, and the RAE

Table 2 describes the average, best, and worst scores of male long jump, female long jump, male high jump, female high jump U18, U20 age groups, and professional group athletes.

Table 3 presents the number of athletes and their performance scores in the long jump and high jump events for men and women across the U18, U20, and professional stages, analyzed over four quarters. The results reveal different degrees of RAE within each group (except for the senior male high jump). Specifically, in the U18 category, there is a high RAE for men's high jump, a moderate RAE for men's and women's long jump, and a low RAE for women's high jump.

Table 2. The number of athletes and their scores in the top 100 for the U18, U20, and senior groups.

	Age group	*N*	M ± SD	Max	Min
Man Long Jump (m)	U18	129	7.46 ± 0.23	8.12	7.03
	U20	190	7.76 ± 0.19	8.35	7.42
	Senior	222	8.20 ± 0.17	8.73	7.88
Women Long Jump (m)	U18	202	6.14 ± 0.16	6.68	5.79
	U20	227	6.33 ± 0.15	6.83	6.02
	Senior	208	6.78 ± 0.17	7.31	6.48
Man High Jump (m)	U18	132	2.12 ± 0.05	2.26	2.01
	U20	233	2.19 ± 0.04	2.33	2.1
	Senior	215	2.30 ± 0.04	2.43	2.22
Women High Jump (m)	U18	213	1.81 ± 0.04	1.96	1.73
	U20	256	1.84 ± 0.04	2.04	1.77
	Senior	206	1.94 ± 0.05	2.08	1.86

In the U20 category, a high RAE is observed for men's long jump, a moderate RAE for women's long jump and men's high jump, and a low RAE for women's high jump. Conversely, in the professional stage, RAE levels are generally lower across all events, with low RAE observed for men's and women's long jump as well as women's high jump, and no RAE detected for men's high jump. Analysis of individual events indicates that the women's high jump consistently exhibits the lowest RAE levels, and across genders, RAE levels are higher for males compared to females. There are no statistically significant differences in athletic performance across the various age and gender groups.

The number of athletes, their scores, and the RAEs across the five continents

Figure 1 illustrates the results of RAE incidence and performance differences across the U18, U20, and senior categories among the five continents, with letters representing the levels of RAE presence. In the men's long jump, no significant intercontinental differences were found for the U18 group (H = 4.961, P = 0.291) or the U20 group (H = 7.344, P = 0.119). However, significant differences were observed in the professional group (H = 14.106, P < 0.01).

The continental performance differences in the senior group were mainly between the Americas (M = 8.22 [8.13, 8.34]) and Asia (M = 8.14 [8.06, 8.28]), and between the Americas and Europe (M = 8.14 [8.06, 8.25]). In terms of RAE levels, Asia (OR Q1/Q4 = 1.75, 95% CI (0.81, 3.78) and Europe (OR Q1/Q4 = 1.83, 95% CI (1.10, 3.04) were classified as level c, while the Americas (OR Q1/Q4 = 1.00, 95% CI (0.58, 1.72) were classified as level d.

In the women's long jump, significant intercontinental differences were found in the U18 group (H = 10.155, P < 0.05), mainly between the Americas (M = 6.17 [6.07, 6.34]) and Oceania (M = 6.04 [5.95, 6.12]). In terms of RAE levels, Americas (OR Q1/Q4 = 3.00, 95% CI (1.20, 7.49) was classified as level a and Oceania (OR Q1/Q4 = 1.33, 95% CI (0.37, 4.81) as level c. No significant differences were observed in the U20 (H = 3.384, P = 0.496) or professional (H = 3.512, P = 0.479) groups. For both men's and women's high jump, no significant intercontinental performance differences were found in any of the three age groups.

The transition rate (TR) from U18 and U20 athletes to the senior group

Table 4 shows the number and percentage of athletes in the U18 and U20 groups who successfully transitioned to higher levels and age categories. The transition rate from U18 to U20 is generally high across events, with the highest in women's high jump at 63.38% and the lowest in men's long jump at 47.65%. In women's high jump, Q4 athletes (71.79%) had a higher transition rate than Q1 athletes (69.01%).

Among U18 and U20 athletes transitioning to the Senior group, the lowest rate was in U18 women's long jump (15.35%), while the highest was in U20 women's high jump (36.49%).Overall, the transition rates from the youth groups to the professional level are relatively low, but there is a slight increase with age (men's long jump: U18: 17.05%, U20: 22.75%; men's high jump: U18: 16.67%, U20: 33.48%; women's long jump: U18: 15.35%, U20: 28.63%; women's high jump: U18: 22.54%, U20: 36.49%).

Table 3. RAE values and Non-parametric Test (Kruskal-Wallis Test) for quarterly scores in the U18, U20, and senior groups.

		N	Q1		Q2		Q3		Q4		OR [95%CI] (Q1/Q4)	*H*	*p*
			%	M (P_{25},P_{75})	%	M (P_{25},P_{75})	%	M (P_{25},P_{75})	%	M (P_{25},P_{75})			
U18	Man Long Jump	129	41.4	7.44 (7.31,7.57)	25.8	7.50 (7.32,7.64)	18.0	7.41 (7.27,7.58)	15.6	7.35 (7.28,7.45)	2.65 [1.69,4.17]	4.948	0.176
	Women Long Jump	202	39.1	6.13 (6.02,6.23)	28.7	6.11 (6.07,6.22)	17.3	6.15 (6.00,6.31)	14.9	6.10 (5.98,6.24)	2.62 [1.81,3.81]	0.617	0.893
	Man High Jump	132	38.6	2.10 (2.06,2.15)	32.6	2.10 (2.08,2.16)	17.4	2.11 (2.09,2.14)	11.4	2.15 (2.08,2.18)	3.39 [2.01,5.71]	1.496	0.683
	Women High Jump	213	33.3	1.80 (1.78,1.83)	28.6	1.80 (1.78,1.82)	19.7	1.79 (1.78,1.82)	18.3	1.80 (1.77,1.84)	1.82 [1.29,2.56]	0.818	0.854
U20	Man Long Jump	190	40.5	7.74 (7.63,7.86)	26.3	7.76 (7.66,7.93)	22.6	7.67 (7.59,7.76)	10.5	7.68 (7.58,7.91)	3.86 [2.46,6.05]	6.745	0.080
	Women Long Jump	227	36.1	6.29 (6.21,6.44)	29.5	6.32 (6.21,6.41)	21.1	6.30 (6.21,6.41)	13.2	6.29 (6.20,6.39)	2.73 [1.88,3.98]	0.963	0.810
	Man High Jump	233	35.2	2.19 (2.15,2.22)	27.9	2.19 (2.15,2.23)	20.2	2.16 (2.15,2.20)	16.7	2.17 (2.15,2.20)	2.11 [1.51,2.95]	5.001	0.172
	Women High Jump	256	31.3	1.83 (1.81,1.86)	28.9	1.84 (1.82,1.87)	20.3	1.84 (1.80,1.87)	19.5	1.85 (1.81,1.87)	1.61 [1.18,2.18]	1.060	0.787
Senior	Man Long Jump	222	32.4	8.19 (8.08,8.29)	21.6	8.16 (8.07,8.27)	24.8	8.19 (8.10,8.34)	21.2	8.16 (8.09,8.29)	1.53 [1.11,2.10]	1.866	0.601
	Women Long Jump	208	28.8	6.74 (6.63,6.85)	27.9	6.77 (6.66,6.94)	23.6	6.75 (6.65,6.92)	19.7	6.74 (6.68,6.87)	1.46 [1.03,2.07]	1.056	0.788
	Man High Jump	215	24.7	2.30 (2.27,2.33)	29.3	2.28 (2.26,2.32)	25.1	2.31 (2.28,2.33)	20.9	2.29 (2.27,2.31)	1.18 [0.83,1.68]	5.041	0.169
	Women High Jump	206	28.6	1.94 (1.92,1.97)	25.2	1.93 (1.90,1.95)	24.8	1.92 (1.90,1.96)	21.4	1.93 (1.90,1.96)	1.34 [0.95,1.88]	5.251	0.154

In the table, OR refers to the ratio of Q4 to Q1 athletes: OR < 1.22 indicates no significant RAE; 1.22 ≤ OR < 1.86 indicates a small RAE; 1.86 ≤ OR < 3.00 indicates a medium RAE; and OR ≥ 3.00 indicates a large RAE.

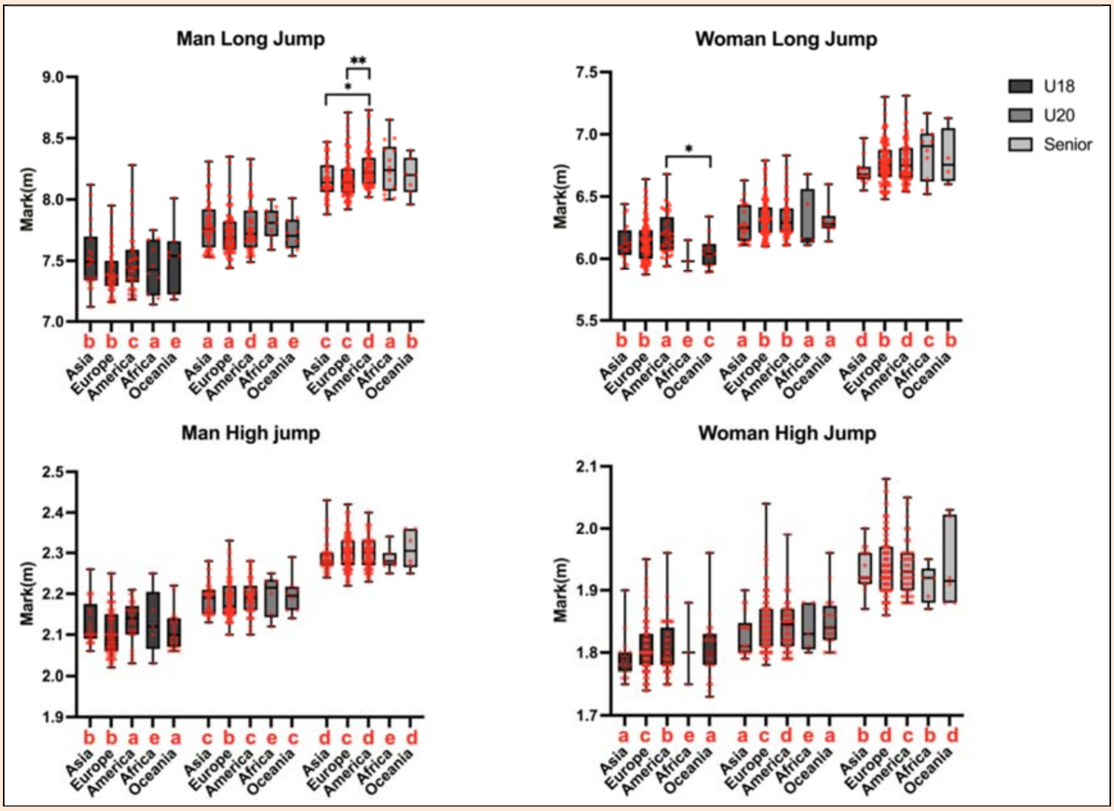

Figure 1. **Non-parametric Test (Kruskal-Wallis Test) of continent scores within U18, U20, and senior groups.** 1-) *, $p < 0.05$; **, $p < 0.01$; 2-) a, large RAE; b, medium RAE; c, small RAE; d, without RAE; e, missing data with no RAE value. 3-) The sample size of the following groups is less than 10 athletes; therefore, they were not included in the non-parametric tests: Africa (U18, U20 women's long jump, men's and women's high jump; Senior men's and women's high jump) and Oceania (U18 men's long jump; U20 women's long jump, men's high jump; Senior men's and women's long jump, high jump).

Table 4. **The transition rates of U18 to U20 and U18, U20 athletes to the senior group.**

		N	n	TR (%)				
				Q1	Q2	Q3	Q4	Sum
U18 to U20	Man Long Jump	129	61	54.71	46.85	52.17	20.00	47.65
	Women Long Jump	202	113	58.23	62.07	57.14	36.67	55.94
	Man High Jump	132	67	49.02	51.16	56.52	46.67	50.76
	Women High Jump	213	135	69.01	60.66	50.00	71.79	63.38
U18 to senior	Man Long Jump	129	22	22.64	12.12	21.74	5.00	17.05
	Women Long Jump	202	31	11.39	18.97	22.86	10.00	15.35
	Man High Jump	132	22	11.76	23.26	13.04	20.00	16.67
	Women High Jump	213	48	18.31	27.87	16.67	28.21	22.54
U20 to senior	Man Long Jump	190	53	35.06	16.00	20.93	40.00	22.75
	Women Long Jump	227	65	25.61	29.85	31.25	30.00	28.63
	Man High Jump	233	76	29.27	41.54	23.40	35.90	33.48
	Women High Jump	256	81	27.50	29.73	34.62	38.00	36.49

N, the number of athletes meeting the selection criteria; *n*, the number of athletes successfully transitioning to the U20 or senior group;Q1, first quartile; Q2, second quartile; Q3, third quartile; Q4, fourth quartile

Additionally, the transition rates for high jump events are generally higher than those for long jump events. Considering relative age, it is observed that, except for the U18 men's long jump and women's long jump, athletes in the U18 and U20 high jump events, as well as the U20 long jump, with relatively younger ages (Q4) have a higher transition rate to the professional level compared to their relatively older counterparts (Q1). This indicates a prevalent "relative age effect reversal" among younger athletes.

Table 5 illustrates the proportion of athletes from U18 and U20 age groups across five continents who successfully transition to the professional level. Generally, the number of athletes and transition rates from the U20 group to the professional level are higher compared to the U18 group. The highest transition rate was in Africa's U20 men's high jump (57.14%), while the lowest transition rates were in Africa's U18 women's high jump (0%), U18 women's long jump (0%), and Asia's U18 women's long jump (0%).Both the Americas and Europe have a relatively high number of athletes successfully transitioning to the professional level, with the Americas exhibiting a higher overall transition rate compared to Europe.

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Table 5. The transition rates of U18 and U20 athletes from each continent to the senior group.

		Asia			Europe			America			Africa			Oceania		
		N	*n*	TR (%)	*N*	*n*	TR (%)	*N*	*n*	TR (%)	*N*	*n*	TR (%)	*N*	*n*	TR (%)
U18	Man Long Jump	22	4	18.18	51	7	13.73	39	8	20.51	10	1	10.00	7	2	28.57
	Women Long Jump	19	0	0.00	126	21	16.67	41	9	21.95	3	0	0.00	13	1	7.69
	Man High Jump	24	4	16.67	61	8	13.11	23	6	26.09	5	2	40.00	19	2	10.53
	Women High Jump	15	1	6.67	131	33	25.19	41	10	24.39	3	0	0.00	23	4	17.39
U20	Man Long Jump	51	13	25.49	71	21	19.57	47	13	27.66	11	3	27.27	10	3	30.00
	Women Long Jump	22	3	13.64	129	38	29.46	62	20	32.26	5	2	40.00	9	2	22.22
	Man High Jump	42	15	35.71	118	35	29.66	58	20	34.48	7	4	57.14	8	2	25.00
	Women High Jump	18	2	11.11	165	60	36.36	52	13	25.00	5	1	20.00	16	5	31.25

N, the number of athletes meeting the selection criteria; *n*, the number of athletes successfully transitioning to the senior group; TR (%), the proportion of athletes who successfully transitioned.

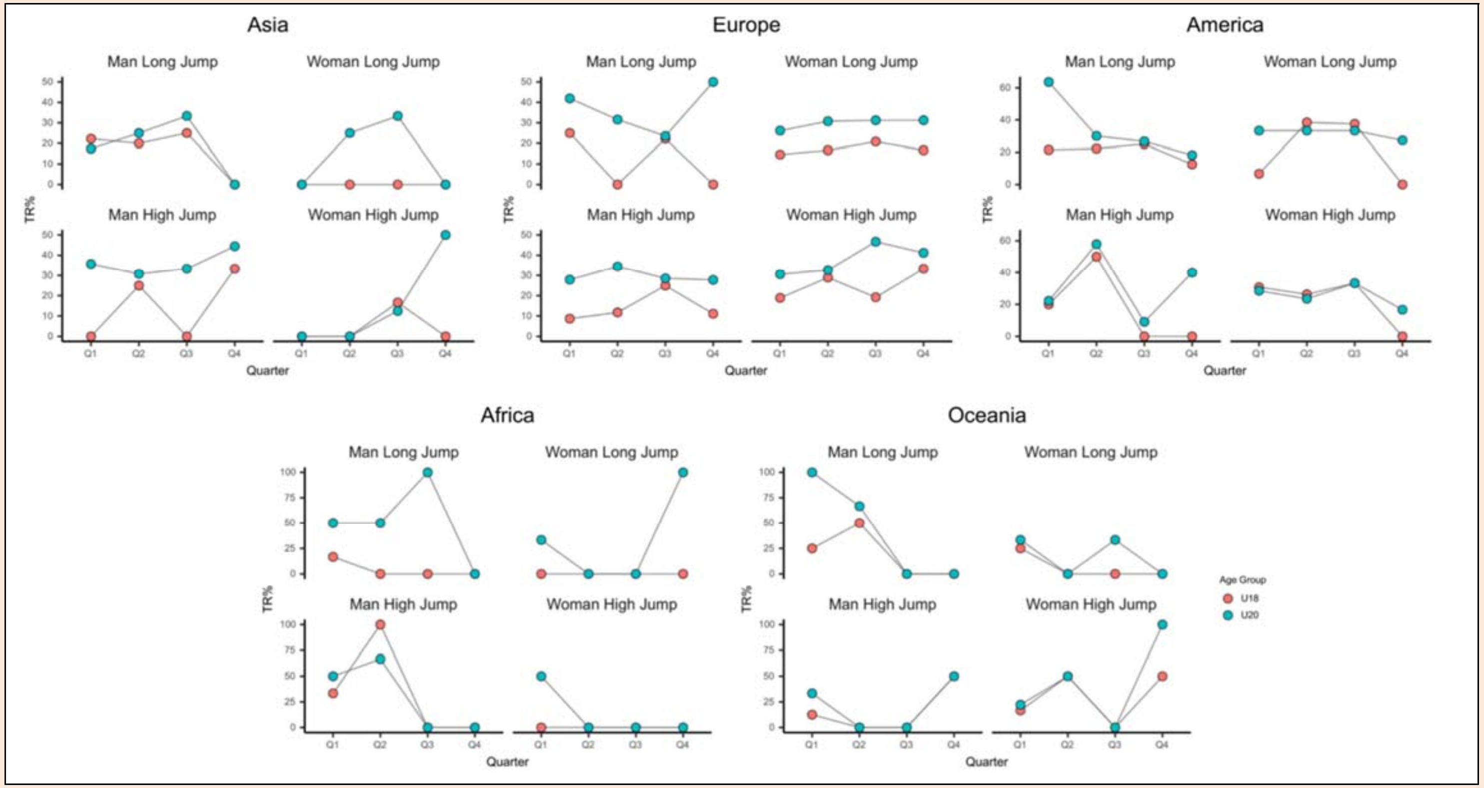

Figure 2. The transition rates of U18 and U20 athletes to the senior group in five continents.

Figure 2 illustrates the quarterly transition rates of U18 and U20 athletes across the five continents as they progress to the senior category. In each continent, the transition rates for U20 athletes were generally higher than those for U18 athletes. The higher transition rate of Q4 athletes compared to Q1 athletes indicates the presence of the "advantage reversal" phenomenon. This phenomenon was observed in the following cases: men's high jump and U20 women's high jump in Asia; U20 men's long jump, women's long jump, U18 men's high jump, and women's high jump in Europe; U20 men's high jump in the different levels of athletic proficiency. In terms of distribution, the proportion of athletes in the AS group increases as athletic proficiency improves (from TOP100 to TOP20); Americas; U20 women's long jump in Africa; and both men's and women's high jump in Oceania.

Age and performance differences between the "all-phase success" and "senior success" groups across different levels of athletic proficiency

Table 6 illustrates the presence of RAE and the age-performance profiles across career stages for "all-phase success (AS)" and "senior success (SS)" groups of jump athletes at except for men's long jump, the AS group consistently comprises a larger number of athletes across all levels in other events. Overall, RAE is observed in the AS group, while the SS group shows no RAE or non-significant RAE results. Regarding age across career stages, athletes in the AS group tend to be significantly younger than those in the SS group. The performance differences between AS and SS groups at different levels of athletic proficiency are generally similar. In men's high jump, athletes in the AS group achieve higher best and average TOP performances compared to the SS group.

Table 6. Independent samples t-tests between "all-phase success (AS)" and "senior success (SS)" groups within TOP20, TOP50, and TOP100 categories in the senior group.

			N	%	OR[95%CI] (Q1/Q4)	Age1		Age2		Age3		Performance1		Performance2		Performance3		Performance4	
						M	T	M	t	M	t	M	t	M	t	M	t	M	t
Man Long Jump	TOP 20	AS group	20	44.44	8.00[1.10,58.19]	16.35	-6.067***	18.90	-4.362***	23.35	-3.148**	7.29	-0.363	8.10	1.461	8.45	1.596	8.30	1.678
		SS group	25	55.56	1.80 [0.70,4.62]	18.40		20.88		26.40		7.33		8.04		8.40		8.25	
	TOP50	AS group	48	41.38	1.99 [0.94,4.21]	16.27	-9.297***	19.54	-4.909***	22.85	-5.159***	7.21	-0.73	8.05	1.471	8.32	1.635	8.15	1.13
		SS group	68	58.62	1.20 [0.66,2.18]	18.32		21.40		25.59		7.26		8.02		8.27		8.12	
	TOP 100	AS group	75	33.78	3.56 [1.83,6.93]	16.36	-11.52***	20.07	-6.593***	23.05	-5.213***	7.24	0.064	8.02	1.164	8.23	1.422	8.06	0.545
		SS group	147	66.22	1.05 [0.72,1.54]	18.33		22.28		25.15		7.24		8.00		8.19		8.05	
Women Long Jump	TOP 20	AS group	32	76.19	1.49 [0.60,3.71]	15.68	-5.078***	18.79	-6.644***	25.32	-0.312	5.95	0.059	6.61	-0.703	6.98	0.775	6.85	0.807
		SS group	10	23.81	0.33 [0.04,2.69]	17.70		22.00		25.70		5.95		6.64		6.93		6.81	
	TOP 50	AS group	64	57.14	2.01 [1.02,3.94]	15.60	-7.58***	19.54	-9.214***	24.94	-2.324*	5.87	-1.051	6.60	0.064	6.90	2.386*	6.77	3.465***
		SS group	48	42.86	0.78 [0.40,1.55]	18.04		22.79		26.33		5.93		6.59		6.84		6.68	
	TOP 100	AS group	105	50.48	2.13 [1.26,3.62]	15.63	-8.845***	19.86	-10.403***	24.07	-3.981***	5.80	-0.769	6.58	0.335	6.81	3.005**	6.68	0.942
		SS group	103	49.52	1.04 [0.64,1.67]	18.12		23.21		25.84		5.83		6.58		6.74		6.63	
Man High Jump	TOP 20	AS group	39	67.24	1.83 [0.75,4.46]	16.67	-4.368***	19.59	-3.472**	24.95	-0.12	2.10	1.181	2.27	0.247	2.35	1.907	2.33	2.652*
		SS group	19	32.76	0.25 [0.03,2.05]	18.00		21.16		25.05		2.07		2.27		2.34		2.30	
	TOP 50	AS group	75	63.56	1.92 [1.03,3.57]	16.55	-7.064***	20.01	-4.703***	24.44	-1.575	2.07	0.458	2.26	0.247	2.33	2.036*	2.30	2.293*
		SS group	43	36.44	0.45 [0.17,1.20]	18.07		21.84		25.37		2.06		2.26		2.32		2.28	
	TOP 100	AS group	126	58.60	1.78 [1.12,2.82]	16.48	-8.959***	20.15	-6.882***	23.51	-2.336*	2.07	1.471	2.26	0.934	2.31	2.253*	2.27	2.77**
		SS group	89	41.40	0.61 [0.34,1.11]	18.02		22.07		24.47		2.06		2.26		2.29		2.26	
Women High Jump	TOP 20	AS group	39	86.67	1.55 [0.76,3.16]	15.49	-4.049***	17.85	-4.425***	24.92	-0.19	1.76	0.923	1.88	0.857	2.00	2.103*	1.97	1.712
		SS group	6	13.33	1.00 [0.20,4.96]	17.50		20.83		25.17		1.74		1.88		1.97		1.95	
	TOP 50	AS group	93	81.58	1.66 [1.00,2.77]	15.51	-4.597***	18.73	-5.171***	23.57	-3.413***	1.75	0.879	1.89	-0.816	1.97	0.824	1.94	0.477
		SS group	21	18.42	0.55 [0.22,1.38]	17.33		21.52		26.24		1.73		1.89		1.96		1.93	
	TOP 100	AS group	144	69.90	1.73 [1.13,2.64]	15.43	-7.453***	19.00	-9.115***	23.10	-3.968***	1.74	2.041*	1.88	0.012	1.95	0.848	1.92	-0.244
		SS group	62	30.10	0.78 [0.43,1.42]	17.44		22.39		25.05		1.71		1.88		1.94		1.92	

N: the number of senior group athletes; RAE: the value of RAE; %: the proportion of "AS" or "SS"/N; Age1: the age of first entry into the database; Age2: the age at entry into the senior group; Age3: the age at which best performance; Performance1: the performance of first entry into the database; Performance2: the performance of entry into the senior group; Performance3: best performance; Performance4: the average of the personal top 10 performances: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

In women's long jump, athletes in the AS group achieve higher best performances than those in the SS group. For women's high jump, athletes in the AS group perform better in initial entry scores compared to the SS group

Discussion

One of the main causes of RAE is that relatively older athletes in adolescence gain a performance advantage due to physical maturity, leading to their higher representation in the same age group (Cobley et al., 2009; Malina et al., 2007). However, studies have found no significant performance differences between relatively older and younger athletes at the same competitive level (Norikazu Hirose, 2009; Deprez, 2013; Ulbricht et al., 2015). Thus, it is worth exploring whether early success in youth can explain the differences in RAE incidence and performance among successful senior athletes.

Brustio et al. (2019; 2023a) selected world track and field athletes for studies on the relationship between the RAE and performance based on athletes who ranked in the world top 100 at least once during a given period (e.g., 2020-2019). However, to account for performance discrepancies caused by uneven competition opportunities in specific years (e.g., 2020) - such as the men's long jump top-100 entry marks of 7.94m (2019), 7.72m (2020), and 7.95m (2021) - and to enhance the consistency of selected athletes' performances, this study adopted stricter criteria, requiring athletes in the U18, U20, and senior categories to have at least two valid performances. Of course, this study does not deny the excellence of those athletes who achieved a top 100 world ranking at least once.

Regional performance and RAE disparities

The paper first describes the overall performance and RAE in high jump and long jump events. The data in Table 3 demonstrate that RAE is present across all events, genders, and age categories, with the exception of the negligible RAE incidence in professional male high jump athletes. The overall RAE incidence is lower in females compared to males (with significantly higher RAE values for males in the U18\U20 high jump and U20 long jump categories). As the level of competition increases, the incidence of RAE decreases (in the U18 and U20 categories, there are 2 cases of high RAE, 4 cases of moderate RAE, and 2 cases of low RAE, whereas in the senior category, there are 3 cases of low RAE and 1 case of no RAE). These findings align with previous studies by Romann and Cobley (2015), Brazo-Sayavera et al. (2016; 2018), Kearney et al. (2018), and Brustio et al. (2019) on RAE in athletics, consistent with the general trends summarized by Cobley et al. (2009) and Smith et al. (2018) in sports.

Brustio et al. (2022; 2024a) demonstrated that older athletes tend to outperform younger ones during adolescence, a finding also confirmed by this study, where Q1 athletes showed higher transition rates from U18 to U20 compared to Q4 athletes, with the exception of women's high jump (TR: Q1, 69.01%; Q4, 71.79%). In terms of performance, there were no significant differences in results across the four quartiles for U18, U20, and Senior athletes. One reason for this is the selection criteria used in this study, which required athletes to have at least two valid performances. This higher standard of athletic performance likely minimized the differences between athletes from different quartiles.

Second, the performance and RAE differences among the five continents were described. In Figure 1, the red dots represent valid athlete performances, with their density indicating that athletes are primarily concentrated in Asia, Europe, and the Americas.

In men's long jump performance, the senior group from the Americas (M = 8.22 [8.13, 8.34]) had significantly higher results than those from Asia (M = 8.14 [8.06, 8.28]) and Europe (M = 8.14 [8.06, 8.25]). The RAE levels for the Americas in men's long jump were consistently among the lowest across continents in the U18 (c, small RAE), U20 (d, no RAE), and Senior (d, no RAE) groups (see Figure 1). The relatively low prevalence of RAE in the Americas for men's long jump suggests a reduced early talent dropout rate among younger athletes, which may be one of the reasons why the Americas perform significantly better than Asia and Europe at the senior level.

The transition rates (TR) of Relative Age Effect (RAE)

The transition rate from youth athletes (U18 and U20) to the professional level is generally low, ranging from a minimum of 15.35% for U18 female long jumpers to a maximum of 36.49% for U20 female high jumpers. However, compared to the transition rates reported by Boccia et al. (2021a) for the top 50 jumpers (including high jump, long jump, triple jump, and pole vault) globally, where the transition rates from youth (U18) to professional level were 8% for males and 16% for females, this study reveals that the transition rates for U18 athletes (16.86% for males and 19.04% for females) are higher. Specifically, the transition rate for males has doubled, while the rate for females has increased by 3%. The reason may be that the selection criteria in this study set a higher performance requirement, which increased the likelihood of athletes succeeding. In terms of overall transition rates, the U18 (22.54%) and U20 (36.49%) groups show that the highest transition rates are in the women's high jump. Boccia et al. (2017) also found that most top junior athletes in women's high jump go on to become top senior athletes.

When calculating the transition rates from youth (U18 and U20) to the professional level based on birth quarters (Q1, Q2, Q3, Q4), the results presented in Table 4 show that, except for the U18 long jump event, the remaining groups exhibit a phenomenon of "reversal of advantage" (McCarthy and Collins, 2014). This means that relatively younger athletes (Q4) have a higher success rate in transitioning to a professional career. The increased occurrence of "advantage reversal" results in the U20 group also indicates that the "advantage reversal" effect becomes more pronounced with age.

The "advantage reversal" in high jump is approximately 3% higher than in long jump (based on the difference in Q4 and Q1 transition rates). Tønnessen et al. (2015) showed that long jump performance improves slightly faster than high jump during adolescence. This suggests that the relative age gap creates greater performance differences in long jump, giving older athletes a larger advantage and making it harder for younger athletes to catch up, resulting in less "underdog advantage" compared to high jump.

As shown in Figure 2, European athletes have a higher opportunity for "advantage reversal" compared to athletes from other continents, while in the Americas, older athletes still have an advantage in transitioning to a professional career, with the exception of U20 male high jumpers who show "advantage reversal." Figure 1 shows that European RAE levels are higher than those in the Americas, except for U18 women's long jump, men's and women's high jump, and senior women's high jump. Cobley et al. (2009) and Smith et al. (2018) noted that greater competition intensity increases RAE risk, while Gibbs et al. (2012) found that relatively younger athletes who overcome physical ability gaps in youth may have an advantage in adulthood, leading to an "underdog advantage." Therefore, it is speculated that a higher RAE prevalence within a region may increase the likelihood of "underdog advantage" occurring among younger athletes.

Due to the small sample sizes in some groups from Asia, Africa, and Oceania, these results lack overall reference significance. Descriptive results for continents lacking sufficient data are presented, but data for regions with fewer than 10 people are excluded from Kruskal-Wallis test for inter-regional performance. The significant differences in transition rates between the Americas and Europe, as well as the notable differences in RAE levels shown in Figure 1, may be influenced by factors such as regional economics, policies, and the popularity of sports (Wattie et al., 2015). The reasons for the differences in RAE and the prevalence of "underdog advantage" between regions still warrant further exploration.

"AS", "SS" groups and athletic performance

In studies related to athletic performance in track and field jumping events, Boccia et al. (2017) analyzed the competition age and performance of top Italian athletes (ranked in the top 1% - 4%) compared to other ranked athletes. Additionally, Boccia et al. (2021a) examined the career trajectories of athletes who ranked in the top 50 globally in youth (U18) and senior categories, but no research has yet explored whether early career success influences the performance of already successful professional athletes.

Therefore, this study collects and distinguishes the youth performance of professional athletes across different competitive levels (TOP100, TOP50, TOP20), categorizing them into AS and SS groups based on whether they achieved success before the age of 20. Taking TOP100 results as an example, the RAE prevalence results reveal distinctly different scenarios between the two groups. In the AS group, male long jumpers exhibit a high RAE, female long jumpers show moderate RAE, and male and female high jumpers both demonstrate low RAE. In contrast, in the SS group, RAE is negligible for male and female long jumpers, and for high jumpers, the RAE value is less than 1, indicating that the number of athletes born in the later quarters exceed those born in the first quarter, resulting in a reversed RAE outcome. The distinct delineation observed here partially explains the higher RAE in youth categories (U18, U20) and its reduction in professional categories. Table 7 illustrates significant differences between the AS and SS groups across three age metrics. Athletes in the SS group tend to be 2-3 years older than those in the AS group. However, in terms of performance: 1) There is no significant difference between AS and SS groups in male long jump. 2) Female long jump and male high jump athletes in the AS group maintain an advantage in their best performances. 3) Male high jumpers in the AS group demonstrate higher and more consistent performance (average top 10 results). 4) Initially, female high jumpers in the AS group outperform those in the SS group in entry-level performances, but this advantage diminishes over time. As competitive level increases, the proportion of AS group athletes grows, widening the RAE disparities between the two groups. Similar outcomes are observed across other competitive levels, where age and performance differences between AS and SS groups persist consistently.

In general, it can be inferred that although relatively younger athletes who achieve success later in certain projects and groups may experience a "reverse advantage" in transition success rates during their youth, athletes in the AS group, where the majority are relatively older, still hold the advantage at the peak of their careers. Tønnessen et al. (2015) noted that even at later ages, early-maturing boys maintain an advantage in strength and power tasks. This suggests that in some projects, the technical and strenght advantages accumulated by athletes who succeed earlier may be difficult for those who succeed later, despite overcoming physical disadvantages (Gibbs et al., 2012). This also underscores how selection biases due to RAE likely deprive some talented younger athletes of opportunities to accumulate advantages earlier, thus hindering their ability to achieve better athletic performance in their future careers.

Due to insufficient data after screening in this study, some regions have a disproportionately low number of athletes, which affects the accuracy of the RAE results in those areas.

This study further confirms the presence of RAE across different age groups (U18, U20, senior) in the track and field events of high jump and long jump. It also highlights gender differences, with RAE being more prominent in males than in females. Additionally, the level of RAE decreases with age and competitive level, and there are notable differences in RAE incidence across the five continents.

Finally, this study proved that younger athletes generally have higher transition rates during their youth compared to older athletes. However, it also introduces the novel finding that athletes in the AS group, where there are proportionately older athletes, exhibit superior athletic performance in certain events compared to athletes in the SS group.

Conclusion

In the high jump and long jump events, the distribution of RAE across three different stages shows that males exhibit higher RAE than females, and RAE tends to decrease with higher competitive levels, which generally aligns with the typical patterns observed in sports. There are no performance differences related to relative age among athletes in the high jump and long jump across the U18, U20, and Senior groups. Significant regional differences exist across age groups in the men's long jump event, with Asian athletes exhibiting higher RAE during youth stages (U18, U20), whereas there is no significant RAE among professional athletes from the Americas. There are no differences in athletic performance related to relative age among athletes in the high jump and long jump across the U18, U20, and Senior groups. Athletes in the AS group are consistently 2-3 years younger at key stages of their careers compared to those in the SS group. Although younger athletes generally have higher transition rates during their youth compared to older athletes, athletes in the AS group, which includes a higher proportion of older athletes, outperform those in the SS group in long jump and high jump events during their careers.

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Key points

- The relative age effect is present across all age groups (U18, U20, Senior) and both sexes in the high jump and long jump events (except for the senior male high jump).
- Athletes in the all-phase success group are consistently 2-3 years younger at each key stage of their athletic careers compared to those in the senior success group.
- Relatively younger athletes exhibit higher transition rates during their youth period compared to relatively older athletes.

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