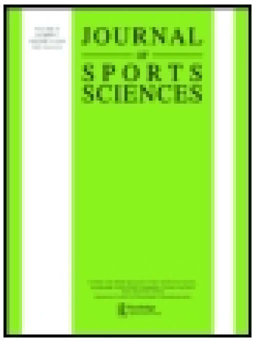

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Sport-specific and non-specific practice of strong and weak responders in junior and senior elite athletics – A matched-pairs analysis

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ABSTRACT

Elite track and field athletes with greater and lesser multi-year performance improvement were compared regarding their developmental sport-specific and non-specific, organised (coach-led) and non-organised (peer-led) sporting activities. Athlete pairs were matched on gender, discipline and baseline performance in competitions (at 13/19 years). Their unequal subsequent performance development during junior (13–17 years; n = 138) and senior (19–23+ years; n = 80) age ranges defined “strong responders” and “weak responders”. Analyses revealed that junior-age strong responders accumulated more organised practice in athletics than weak responders, while the amounts of all other types of activities were indifferent. Senior-age strong responders did not accumulate a greater total sum of all kinds of sport activities or greater amounts of organised practice in athletics or non-organised involvement in athletics or other sports than weak responders. But they engaged in more organised practice and competitions in other sports over more years (9 vs. 2 years) and specialised in athletics at a later age than weak responders (16 vs. 11 years). The results were also robust among senior international medallists vs. national medallists. The findings are reflected relative to the hypotheses of “multiple sampling and functional matching”, “learning transfer as preparation for future learning” and “authenticity of variable learning experiences”.

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Talent development; specific practice; non-specific practice; learning; transfer

Introduction

It is generally accepted that elite athletes acquired expert performance over time in response to participation in developmental sport activities. Issues related to the types and amounts of activities which facilitate the long-term acquisition of exceptional performance, however, have been a matter of debate for many years.

About 25 years ago, Ericsson, Krampe, and Tesch-Römer (1993), Ericsson (2016) postulated that sport-specific, coach-led “deliberate practice” was the only type of activity which would effectively lead to expert performance. They advocated the maximisation of deliberate practice which necessitated early intensification and subsequent continuous expansion of deliberate practice. In contrast, the experiences of many elite athletes included diverse youth sport activities in both coach-led, organised practice (e.g., in sport clubs, high-school sports or sport academies) and peer-led, non-organised activities in both the athlete’s primary sport and other sports. Some authors hypothesised that the diversified juvenile experiences may have benefitted the subsequent development of elite performance (e.g., Côté, Baker, & Abernethy, 2007; Davids, Güllich, Shuttleworth, & Araújo, 2017; Rees et al., 2016, for reviews).

Evidence from empirical observations, however, has been inconsistent in that each type of activity was correlated with performance in some studies but not in others (Davids et al., 2017; Güllich & Emrich, 2014; Macnamara, Moreau, & Hambrick, 2016; for reviews). Nevertheless, two consistencies are apparent when studies are differentiated by the age and performance levels. First, higher levels of *early* performance during *youth* were correlated with greater volumes of organised sport-specific practice, but were not correlated or negatively correlated with involvement in other sports (Diogo & Gonçalves, 2014; Ford, Ward, Hodges, & Williams, 2009; Ford & Williams, 2012; Güllich & Emrich, 2014; Haugaasen, Toering, & Jordet, 2014; Hendry, 2012; San & Lee, 2014; Ward, Hodges, Williams, & Starkes, 2004; Weissensteiner, Abernethy, Farrow, & Müller, 2008). Second and in contrast, *adult world class* athletes (international medallists or top ten) did not accumulate more sport-specific organised practice than their national-class peers, but engaged in more practice in other sports during childhood and adolescence (Carlson, 1988; Güllich, 2014, 2017; Güllich & Emrich, 2013, 2014; Hardy et al., 2013; Hornig, Aust, & Güllich, 2016; Johnson, Tenenbaum, & Edmonds, 2006; Moesch, Elbe, Hauge, & Wikman, 2011; Moesch, Trier Hauge, Wikman, & Elbe, 2013; Van Rossum, 2000).

Talent development during juvenile age ranges purposes to promote athletes’ present performance progress, but also, and perhaps primarily, to expand youngsters’ *potential* for *future development* of performance into adulthood. In this context, early multisport practice experiences have been suggested to expand young athletes’ potential for later long-term improvement in sport-specific performance (Davids et al., 2017; Güllich, 2017). Importantly, the involvement in other sports was considered as *interacting* with long-term sport-

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specific practice and was suggested to improve its later *efficacy* in that equivalent sport-specific practice volumes elicited greater performance improvement. Hypotheses addressing potential underlying reasons have been reviewed (Güllich, 2017). In the context of the available empirical research, an interplay of three related processes has been hypothesised:

- The hypothesis of *"sustainability"*. Diversified engagement is associated with reduced opportunity costs ("time costs"; Güllich & Emrich, 2014) and with reduced risk of overuse injury (DiFiori et al., 2014; Myer et al., 2015, for reviews), and may facilitate prolonged engagement (Butcher, Lindner, & Johns, 2002; Fraser-Thomas, Côté, & Deakin, 2008).
- The hypothesis of *"multiple sampling and functional matching"*. The selection of a main sport emerges from an athlete's experiences in various sports, which increases the probability of electing a sport in which the athlete is particularly talented (Güllich & Emrich, 2014).
- The hypothesis of *"learning transfer as preparation for future learning"*. Athletes acquire a wider and more closely-meshed "network" of perceptual-motor skills, which facilitates the emergence of functional *skill solutions*. In addition, experience with more diversified practice designs and learning modes in multifarious tasks and situations facilitates the emergence of functional *learning solutions* (Bransford & Schwartz, 1999; Davids et al., 2017; Güllich, 2017).

The question of which early sport-specific and non-specific activities expand young athletes' *potential* for *future* long-term development of performance is critical in talent development. Investigating it more purposefully and stringently has implications for the investigational approach. The formal logic requires to examine: what types and amounts of activities during an *earlier*, multi-year period of time lead to greater or lesser *later* improvement in performance *over time* during a *subsequent*, multi-year period? Previous research has typically considered performance in a *single measurement* (current performance or eventual peak performance), but has not considered the *development* of performance through the different age periods of a sporting career.

The present study addresses this issue in a sample of elite track and field athletes by comparing athletes with greater and lesser levels of multi-year performance *improvement over time* using a matched-pairs design (Thomas, Nelson, & Silverman, 2005). The athletes were paired by gender, track and field discipline and baseline level of performance; paired athletes differed, however, in *subsequent* performance *development* defined as *"strong responders"* and *"weak responders"*. The study investigated the empirical question whether strong and weak responders within *junior* and within *senior* age categories differed in their current and earlier sport activities. The question is both practically relevant and theoretically pivotal.

The deliberate practice framework predicts that, equally within junior and senior age ranges, greater performance improvement is correlated with greater amounts of specific, organised, coach-led practice in athletics but not with any other type of sport activity, just as empirical research suggests for *early junior* performance (see above). Alternatively, existing retrospective studies and the hypotheses specified above suggest that accumulated specific practice in athletics alone does not differentiate performance improvement within *senior* age, but its interaction with earlier practice in other sports does.

Methods

Participants

Officials of the German Athletics Association invited by mail all national squad athletes (n = 528) to participate in the study and provided the link for an online survey. One-half of the national squad participated (n = 264). The sample was representative of the population regarding the different types of disciplines and achieved squad levels (54% junior, 32% senior sub-elite, 14% senior elite), while females were slightly over-represented (57% vs. 51%).

The objective was to compare the sport activities of strong and weak responders during junior (13–17 years) and senior age categories (19–23+ years). All athletes 17+ years of age (for development during junior age; n = 252) and athletes 23+ years of age (development during senior age; n = 122) were included in a matching procedure.

Matching procedure

Participation patterns and the probability of success may vary across disciplines and by gender. In addition, the performance level attained at 13 or 19 years may affect subsequent improvement in performance. To address these issues, pairs of athletes were matched on gender, track and field discipline and baseline performance (championship level and placing at age 13/19 years), but differed on later performance (≥6 ranks apart at 17/23+ years; for the determination of performance and ranks see below).

Strong and weak responders are described by age, gender, discipline and performance levels in Table 1. The matching of strong and weak responders during *junior* age was done as follows: Scanning of the sample identified 34 athletes who had one matched counterpart. In addition, 22 pools of 3–5 matching athletes were identified (identical gender, discipline and baseline performance). This large number reflected the fact that many athletes placed 1st–3rd at county (n = 42) and regional (n = 120) championships at 13 years of age. Within each pool, pairs were randomly assigned, resulting in 35 pairs. Matched junior-age strong and weak responders thus involved 69 pairs (n = 138). They were 54 ± 25 ranks apart at age 17 years (ranks within the subsample).

Because the *senior-age* subsample was smaller and baseline performance at 19 years was more heterogeneous (compared to 13 years; Table 1) matching criteria were applied slightly less restrictively within this subsample. Closely related disciplines (100/200 m, 400/400 m hurdles, 800/1500 m, 3000/5000/3000 m steeplechase, long/triple jump) and baseline (19 years) performance differentials of up to ±2 places within one championship level were considered acceptable matches (e.g., European junior championships 2nd/4th, national

Table 1. Description of the subsamples of athletes with greater and lesser performance improvement (strong and weak responders, respectively) within junior (13–17 years, n = 138; above) and within senior age ranges (19–23+ years, n = 80; below) by age, gender, discipline and performance level.

		Strong Responders	Weak Responders
Performance development 13–17 years			
Age (*M* ± *SD*)		21.6 ± 4.7	22.2 ± 5.0
Gender female		38	38
Track and field disciplines	Sprint events	21	21
	Middle/long distance	19	19
	Jumping events	12	12
	Throwing events	11	11
	Combined events	6	6
Performance level at age 13 years	Regional 1st–3rd	41	41
	Regional 4th–10th	7	7
	County 1st–3rd	16	16
	Below	5	5
Performance level at age 17 years	International 1st–3rd	12	0
	International 4th–10th	15	2
	National 1st–3rd	38	19
	National 4th–10th	4	31
	Regional 1st–3rd	0	17
Rank within the subsample (M ± SD)	Age 13 years[a]	54 ± 45	54 ± 45
	Age 17 years	40 ± 27	94 ± 33
Performance development 19–23+ years			
Age (*M* ± *SD*)		26.3 ± 3.1	26.2 ± 3.7
Gender female		21	21
Track and field disciplines	Sprint events	10	10
	Middle/long distance	13	13
	Jumping events	6	6
	Throwing events	6	6
	Combined events	5	5
Performance level at age 19 years	International 1st–3rd	12	11
	International 4th–10th	8	11
	National 1st–3rd	14	12
	Below	6	6
Performance level at age 23+ years	International 1st–3rd	17	0
	International 4th–10th	16	7
	National 1st–3rd	5	12
	Below	2	21
Rank within the subsample (M ± SD)	Age 19 years	38 ± 22	38 ± 22
	Age 23+ years	22 ± 19	53 ± 16

M – mean, *SD* – standard deviation. [a] Mean rank value considerably below 69 because of the large number of athletes with identical rank at age 13 years, particularly regional and county championships 1st–3rd places.

championships 5th/7th etc.). Scanning of the sample identified 31 athletes who had one matched counterpart and four pools of 3–4 matching athletes. Assignment by random within each pool resulted in six pairs. Finally, three exceptions to the matching rules were accepted. Three (eventual) Olympic medallists had a counterpart who had placed 4–7 places *above* them at the same championship at age 19 years (instead of the criterion differential of ±2 places). In summary, matched senior-age strong and weak responders involved 40 pairs (n = 80). They were 31 ± 18 ranks apart at age 23+ years (ranks within the subsample). The group of senior-age strong responders included 17 medallists at Olympic games, world and European championships and 16 athletes placing 4th–10th (Table 1).

Forty-seven athletes were included in both subsamples for junior and senior-age development.

Questionnaire

Participants responded to an online survey resembling earlier studies (Güllich, 2014, 2017; Hornig et al., 2016). They reported, amongst others, the following variables:

- Age at starting athletics practice, at starting competitions and at individual peak performance.
- Types of activity engaged in (non-organised athletics, non-organised other sports, organised practice and competitions in other sports), for each type of activity: age at start and at cessation of involvement.
- Age at exclusive specialisation in athletics.
- Number and duration of organised practice sessions and non-organised activity in athletics and in other sports within defined age categories: under 11, 12–13, 14–15, 16–17, 18–19, 20–21 and 22+ years.
- Periods of reduced or interrupted practice due to injury or other factors, e.g., educational or occupational time demands.
- Performance level in competitions (highest championship level and placing) within the above age categories. Competitive achievements were computed in a four-digit code: The first digit: age category (senior to under-11); the second: championship level (Olympics/world championships to county level); and the third and fourth digit: attained place. This permitted conversion into ranks within a subsample to describe the relative performance development of each athlete (Table 1).

In addition, athletes' motives for participation in competitive sports (adaptation of Lehnert, Sudeck, & Conzelmann, 2011), injuries, participation in athlete services (physiotherapy, sports medicine, psychology, performance diagnostics etc.; Güllich & Emrich, 2012), family structure, parents' educational level, sport involvement and parental emotional and instrumental support were controlled for (no difference between strong and weak responders; all $p > 0.05$).

Completion of the questionnaire took the athletes 43 ± 10 minutes (*M* ± *SD*). Test-retest reliability of the instrument was examined over 3 weeks and 3 years; reliability was good to very good ($0.80 \le r_{tt} \le 1.00$; Güllich & Emrich, 2014; Hornig et al., 2016). External validity was tested by comparing the questionnaire responses of 29 athletes with their daily training logs over an entire season ($0.81 \le r \le 1.00$). Ethical approval was provided by the German Federal Institute of Sport Science.

Statistical analysis

Estimates of the volumes of activity types are reported as time accumulated within each age category by multiplying the mean weekly time by the annual weeks of involvement (≤11 years: 40 weeks, 12–15: 45, 16–19: 48, 20+ years: 50 weeks/year) and years of involvement within an age category. Calculations considered the exact age at the start and cessation of an activity within an age category. Periods of interruption were subtracted.

Descriptive data include frequencies, means and standard deviations. Differences between strong and weak responders were analysed using χ^2 (McNemar), paired *t*-test or, for non-uniform (skewed) data distribution, the non-parametric Wilcoxon test. Effect sizes (Cohen, 1992) are reported as φ or Cohen's *d* using pooled variance. Analyses were performed with SPSS 24.0. All statistical hypothesis testing was two-tailed. A value of $p < 0.05$ was considered statistically significant.

Results

Strong and weak responders during junior age

Strong and weak responders during junior age did *not* differ significantly ($p > 0.05$): in the total sum of all kinds of sport activities until age 13 years; the years or volume of organised practice or competitions in athletics until age 13 years; participation, duration or volume of involvement in non-organised athletics or in organised or non-organised other sports until age 13 years or at 14–17 years (Table 2). Strong responders were more likely to experience practice and competitions in other sports before entering athletics, and accumulated more organised practice and competitions in athletics from 14 to 17 years than weak responders (Table 2).

Strong and weak responders during senior age

Although the strong and weak responders were identical in age (Table 1), the strong responders achieved their individual peak performance about 3 years later than weak responders (Table 3). That is, they continued to improve in performance over more years.

Strong and weak responders did *not* differ significantly ($p > 0.05$): in juvenile performance development (rank within the sample, respectively: 13 years: 35 ± 22 vs. 32 ± 22; 15 years: 32 ± 22 vs. 36 ± 22; 17 years: 36 ± 23 vs. 40 ± 22; 19 years: 38 ± 22 vs. 38 ± 22); the total sum of all kinds of sport activities throughout the career; years or volume of organised practice or competitions in athletics until age 19 years or at 20–23 years; and participation, duration or volume of non-organised involvement in other sports throughout the career (Table 3).

The strong senior responders differed from the weak responders, in that they were more likely to engage in organised practice and competitions in other sports (Table 3). More strong than weak responders experienced practice and competitions in other sports before entering athletics and accumulated more practice hours in other sports before starting athletics. Strong senior responders also continued to practice and compete in other sports over more years than weak responders, engaged in greater total amounts of practice in other sports and specialised in athletics at a later age, primarily in late adolescence (Table 3).

Besides, strong senior responders were *less* likely to participate in non-organised athletics and their duration of involvement was shorter than among weak responders. Both groups performed small absolute amounts of non-organised athletics and these were, respectively, smaller among strong than weak responders (sum until 19 years 40 ± 204 vs. 123 ± 287 hours, $p < 0.05$; 20–23 years 0 ± 0 vs. 141 ± 333 hours, $p < 0.01$; Table 3).

Characteristics of athletes within the very top margin of the performance continuum are particularly relevant to issues of the *scope* of findings addressed in the Introduction. To this end, 17 medallists at Olympic Games, world and European championships are compared with their matched national medallist peers (1st–3rd at national championships, of these 13 athletes placing 7th–25th at international championships) in Table 4. The findings are fully consistent with those of the entire senior-age sample and effect sizes are in a similar range (Table 3) with one exception. International medallists participated in a greater number of competitions than national medallists at age 20–23 years.

Strong and weak responders within either subsample did not differ in the *types* of other sports in which they engaged. About 66% participated in game sports (males 76%, females 57%; $p < 0.05$) and 61% in non-game sports (males 43%, females 78%; $p < 0.01$). The most frequent game sports were football (35%; males 57%, females 17%), volleyball (19%), handball (14%), tennis (14%) and non-game sports were swimming (21%) and artistic gymnastics (20%; males 6%, females 33%). They attained their highest competitive achievement in other sports (51% county, 37% regional, 12% national level) at 13.4 ± 4.4 years. At that time, 15% did not yet compete in athletics, while 4% competed at a lower level, 57% at the same level and 24% at a higher level in athletics compared to other sports.

Table 2. Types of activities engaged in, age structure of the athletic career, and volume of activity types among athletes with greater and lesser performance improvement (strong versus weak responders) within junior age (13–17 years).

		Strong Responders		Weak Responders		$\chi^2 p$	φ
Activity types athletes engaged in							
Athletics	Non-organised	33%		39%		0.50^{ns}	0.06
Other sports	Total (any setting)	73%		70%		0.14^{ns}	0.03
	Organised practice	70%		64%		0.52^{ns}	0.06
	Competitions	58%		44%		2.90^{ns}	0.15
	Non-organised	41%		30%		1.55^{ns}	0.11
Athletics was first sport	Organised practice	45%		67%		6.61*	0.22
	Competitions	54%		75%		7.12*	0.23
Career age structure		M	*(± SD)*	M	*(± SD)*	*t or Z, p*	*d*
Athletics							
Start age (years)	Total (any setting)	8.3	*(2.8)*	8.1	*(2.9)*	$t = 0.55^{ns}$	0.07
	Organised practice	8.7	*(3.0)*	8.1	*(2.9)*	$t = 1.39^{ns}$	0.21
	Competitions	9.3	*(2.5)*	9.4	*(2.6)*	$t = 0.20^{ns}$	0.03
Duration (years)	Non-organised	2.5	*(4.3)*	3.2	*(5.1)*	$Z = 0.88^{ns}$	0.15
Other sports							
Start age (years)	Total (any setting)	6.1	*(2.2)*	7.2	*(4.0)*	$t = 1.41^{ns}$	0.34
Duration (years)	Organised practice	6.1	*(5.4)*	5.6	*(6.1)*	$Z = 0.42^{ns}$	0.08
	Competitions	3.8	*(4.1)*	2.8	*(4.7)*	$Z = 1.85^{ns}$	0.22
	Non-organised	3.0	*(4.3)*	2.3	*(4.0)*	$Z = 1.13^{ns}$	0.18
Age of specialisation in athletics (years)		13.0	*(5.8)*	12.7	*(6.2)*	$t = 0.37^{ns}$	0.06
Volume of activities							
Athletics							
Competitions (number)	12–13 years	30	*(11)*	27	*(14)*	$t = 1.60^{ns}$	0.24
	14–17 years	69	*(23)*	61	*(20)*	t = 2.30*	0.39
Organised practice (hours)	–11 years	550	*(588)*	550	*(508)*	$Z = 0.29^{ns}$	0.00
	12–13 years	473	*(299)*	415	*(215)*	$t = 1.57^{ns}$	0.22
	14–15 years	792	*(356)*	636	*(275)*	t = 3.57**	0.49
	16–17 years	1194	*(431)*	946	*(366)*	t = 5.41**	0.62
Non-organised (hours)	–11 years	30	*(125)*	29	*(96)*	$Z = 0.26^{ns}$	0.01
	12–13 years	25	*(78)*	18	*(44)*	$Z = 0.09^{ns}$	0.11
	14–15 years	31	*(84)*	36	*(66)*	$Z = 0.93^{ns}$	0.06
	16–17 years	39	*(100)*	43	*(89)*	$Z = 0.41^{ns}$	0.04
Other sports							
Organised practice (hours)	–11 years	476	*(520)*	393	*(657)*	$Z = 1.85^{ns}$	0.14
	12–13 years	130	*(168)*	119	*(190)*	$Z = 0.81^{ns}$	0.07
	14–15 years	120	*(216)*	114	*(210)*	$Z = 0.20^{ns}$	0.03
	16–17 years	50	*(161)*	74	*(224)*	$Z = 1.03^{ns}$	0.12
Before start athletics practice (hours)		335	*(462)*	279	*(484)*	$Z = 1.12^{ns}$	0.12
Non-organised (hours)	–11 years	103	*(201)*	100	*(234)*	$Z = 0.36^{ns}$	0.02
	12–13 years	54	*(98)*	48	*(132)*	$Z = 1.10^{ns}$	0.06
	14–15 years	45	*(91)*	38	*(124)*	$Z = 1.33^{ns}$	0.06
	16–17 years	16	*(53)*	29	*(129)*	$Z = 0.26^{ns}$	0.13

Mean *(±SD)* values. * $p < 0.05$, ** $p < 0.01$, ^{ns} not significant ($p > 0.05$); *d*: Cohen's *d*.

Discussion

Developmental sport activities were compared among matched pairs of German track and field national squad members matched on gender, discipline and baseline performance, but who differed in subsequent multi-year performance development (strong and weak responders) within junior (13–17 years) and senior age ranges (19–23+ years). Junior-age strong responders were more likely to experience practice and competitions in other sports before starting athletics and accumulated more organised athletics practice and competitions at 14–17 years; the amounts of all other types of activities were indifferent.

In contrast, senior-age strong responders did not accumulate more organised practice in athletics or more non-organised, peer-led activities in athletics or other sports than weak responders at any age; rather, they engaged in more organised, coach-led practice and competitions in other sports through childhood and adolescence. More strong responders experienced practice and competitions in other sports before starting athletics compared to weak responders. Strong responders also engaged in greater practice volumes in other sports over more years and specialised in athletics at a later age. The findings were also robust within the very top margin of the performance continuum (international medallists vs. national medallists).

Effect sizes on junior-age performance development were small regarding participation in other sports before starting athletics and the number of competitions at 14–17 years, and were medium regarding the volume of practice in athletics at 14–17 years. Effect sizes for the duration and volume of organised practice and competitions in other sports on senior-age performance development were large.

From an *empirical* perspective, the matched-pairs design precluded potential confounding effects of gender, discipline and baseline performance. In addition, the distinction of strong and weak responders cannot be ascribed to differences in age, prior performance development, total sum of all kinds of sport activities, earlier volume of practice or competitions in athletics, types of other sports, participation in athlete services, motives or parental support.

Table 3. Types of activities engaged in, age structure of the athletic career, and volume of activity types among athletes with greater and lesser performance improvement (strong versus weak responders) within senior age (19–23+ years).

		Strong Responders		Weak Responders		$\chi^2 p$	φ
Activity types athletes engaged in							
Athletics	Non-organised	10%		28%		4.02*	0.22
Other sports	Total (any setting)	83%		55%		7.04**	0.30
	Organised practice	75%		40%		10.03**	0.35
	Competitions	70%		23%		18.15**	0.48
	Non-organised	40%		28%		1.40^{ns}	0.13
Athletics was first sport	Organised practice	40%		85%		13.65**	0.41
	Competitions	55%		90%		12.29**	0.39
Career age structure		M	*(± SD)*	M	*(± SD)*	*t or Z, p*	*d*
Athletics							
Age of individual peak performance (years)		24.0	*(2.6)*	20.9	*(2.2)*	*t* = 5.72**	1.30
Start age (years)	Total (any setting)	9.3	*(3.4)*	8.2	*(2.9)*	$t = 1.54^{ns}$	0.33
	Organised practice	9.5	*(3.6)*	8.4	*(3.0)*	$t = 1.64^{ns}$	0.35
	Competitions	10.0	*(3.0)*	9.0	*(2.6)*	$t = 1.58^{ns}$	0.37
Duration (years)	Non-organised	0.6	*(2.2)*	2.7	*(5.6)*	*Z* = 2.30*	0.49
Other sports							
Start age (years)	Total (any setting)	*7.7*	*(3.2)*	*8.6*	*(3.7)*	$t = 0.94^{ns}$	*0.28*
Duration (years)	Organised practice	*8.8*	*(7.5)*	*2.4*	*(3.6)*	*Z = 4.02***	*1.08*
	Competitions	*5.0*	*(4.7)*	*1.2*	*(2.8)*	*Z = 3.58***	*0.99*
	Non-organised	*2.5*	*(3.6)*	*2.8*	*(5.2)*	$t = 0.32^{ns}$	*0.08*
Age of specialisation in athletics (years)		*15.9*	*(7.6)*	*10.9*	*(5.2)*	*t = 3.71***	*0.76*
Volume of activities							
Athletics							
Competitions (number)	12–15 years	55	*(29)*	58	*(31)*	$t = 0.38^{ns}$	0.08
	16–19 years	73	*(27)*	72	*(21)*	$t = 0.13^{ns}$	0.03
	20–23 years	73	*(27)*	64	*(22)*	$t = 1.62^{ns}$	0.36
Organised practice (hours)	−11 years	410	*(472)*	480	*(480)*	$Z = 0.58^{ns}$	0.15
	12–15 years	953	*(506)*	1098	*(541)*	$t = 1.47^{ns}$	0.28
	16–19 years	2284	*(833)*	2451	*(855)*	$t = 0.98^{ns}$	0.20
	20–23 years	3141	*(999)*	3264	*(1013)*	$t = 1.62^{ns}$	0.12
Non-organised (hours)	−11 years	4	*(25)*	29	*(111)*	$Z = 1.48^{ns}$	0.31
	12–15 years	18	*(77)*	40	*(86)*	$Z = 1.38^{ns}$	0.24
	16–19 years	18	*(106)*	54	*(151)*	$Z = 1.47^{ns}$	0.28
	20–23 years	0	*(0)*	141	*(333)*	*Z* = 3.19**	0.62
Other sports							
Organised practice (hours)	−11 years	538	*(706)*	104	*(198)*	*Z* = 3.74**	0.84
	12–15 years	423	*(424)*	48	*(97)*	*Z* = 4.44**	1.22
	16–19 years	330	*(709)*	22	*(66)*	*Z* = 3.40**	0.61
	20–23 years	40	*(229)*	5	*(20)*	$Z = 0.42^{ns}$	0.21
Before start athletics practice (hours)		476	*(641)*	64	*(176)*	*Z* = 3.53**	0.88
Non-organised (hours)	−11 years	86	*(219)*	63	*(133)*	$Z = 0.39^{ns}$	0.13
	12–15 years	84	*(183)*	48	*(105)*	$Z = 0.59^{ns}$	0.25
	16–19 years	16	*(71)*	29	*(69)*	$Z = 1.20^{ns}$	0.19
	20–23 years	1	*(8)*	35	*(131)*	$Z = 1.63^{ns}$	0.36

Mean *(±SD)* values. * $p < 0.05$, ** $p < 0.01$, ^{ns} not significant ($p > 0.05$); *d*: Cohen's *d*.

The findings are consistent with numerous retrospective studies demonstrating that early intensified sport-specific practice promotes rapid attainment of juvenile performance. The findings are also consistent with studies showing that senior world-class and national-class athletes were not discriminated by the volume of sport-specific practice but were discriminated by the interplay of sport-specific practice with earlier practice experiences in other sports (see Introduction section). The value of the present study is to demonstrate consistent findings in the association of multi-year *longitudinal* performance *development* during junior and senior age ranges with current and earlier sporting activities.

Conceptual and theoretical implications

From a *conceptual* perspective, all subsamples engaged in specific practice in athletics over many years. Still, the "deliberate practice" framework cannot account for the composition of activities that facilitate performance development in *senior elite athletes*. "Early specialisation" and the principle of "ever-more of the same" inherent in the deliberate practice notion fall short of providing explanatory power within high performance ranges in senior elite sports. Exceptional athletes are not "trivial machines" that can be adequately described by a simple input-output relationship.

The present data also do not provide support for the beneficial role of high amounts of non-organised, peer-led play advocated in Côté et al.'s (2007) "Developmental Model of Sport Participation" (consistent in other types of sports: Baker, Côté, & Abernethy, 2003; Güllich, 2014, 2017; Hornig et al., 2016; Memmert, Baker, & Bertsch, 2010; Weissensteiner et al., 2008).

On the other hand, the findings suggest several significant *theoretical* implications. The findings do not question the critical importance of extensive, long-term sport-specific practice. Among elite athletes similarly accumulating considerable sport-specific practice over a long period, however, sport-specific practice per se does not differentiate performance. Rather, the *interplay* of childhood/adolescent practice in other sports with extensive practice in athletics

Table 4. Types of activities engaged in, age structure of the athletic career, and volume of activity types among senior international medallists and national medallists matched on gender, discipline and performance at age 19 years.

		International Medallists		National Medallists		$\chi^2 p$	φ
Activity types athletes engaged in							
Athletics	Non-organised	12%		35%		2.62^{ns}	0.28
Other sports	Total (any setting)	77%		53%		2.06^{ns}	0.25
	Organised practice	77%		29%		7.56**	0.47
	Competitions	65%		18%		7.77**	0.48
	Non-organised	29%		29%		0.00^{ns}	0.00
Athletics was first sport	Organised practice	41%		82%		10.03**	0.54
	Competitions	53%		94%		7.40**	0.47
Career age structure		M	*(± SD)*	M	*(± SD)*	*t or Z, p*	*d*
Athletics							
Age of individual peak performance (years)		24.0	*(2.4)*	20.8	*(2.0)*	*t* = 4.62**	1.44
Start age (years)	Total (any setting)	9.4	*(3.6)*	8.5	*(2.8)*	*t* = 0.94^{ns}	0.29
	Organised practice	9.9	*(4.0)*	8.8	*(3.1)*	*t* = 0.97^{ns}	0.30
	Competitions	10.5	*(2.8)*	9.1	*(2.3)*	*t* = 1.79^{ns}	0.55
Duration (years)	Non-organised	0.4	*(1.1)*	3.2	*(5.7)*	*Z* = 2.12*	0.70
Other sports							
Start age (years)	Total (any setting)	7.4	*(2.5)*	9.9	*(5.1)*	*t* = 1.16^{ns}	0.62
Duration (years)	Organised practice	9.4	*(7.5)*	1.6	*(2.7)*	*Z* = 2.94**	1.39
	Competitions	4.4	*(3.8)*	0.5	*(1.2)*	*Z* = 5.05**	1.37
	Non-organised	2.5	*(4.6)*	2.9	*(5.5)*	*Z* = 0.30^{ns}	0.09
Age of specialisation in athletics (years)		16.7	*(8.0)*	10.1	*(4.9)*	*t* = 3.11**	0.99
Volume of activities							
Athletics							
Competitions (number)	12–15 years	63	*(30)*	54	*(16)*	*t* = 1.03^{ns}	0.38
	16–19 years	81	*(19)*	72	*(16)*	*t* = 1.50^{ns}	0.53
	20–23 years	82	*(23)*	66	*(16)*	*t* = 2.16*	0.80
Organised practice (hours)	−11 years	359	*(493)*	474	*(486)*	*Z* = 0.87^{ns}	0.24
	12–15 years	1076	*(602)*	1214	*(676)*	*t* = 0.70^{ns}	0.22
	16–19 years	2631	*(953)*	2728	*(766)*	*t* = 0.34^{ns}	0.11
	20–23 years	3443	*(925)*	3474	*(763)*	*t* = 0.12^{ns}	0.04
Non-organised (hours)	−11 years	0	*(0)*	26	*(73)*	*Z* = 1.34^{ns}	0.50
	12–15 years	5	*(22)*	56	*(108)*	*Z* = 1.75^{ns}	0.65
	16–19 years	3	*(12)*	93	*(216)*	*Z* = 1.60^{ns}	0.59
	20–23 years	0	*(0)*	234	*(449)*	*Z* = 2.37*	0.74
Other sports							
Organised practice (hours)	−11 years	471	*(492)*	88	*(166)*	*Z* = 2.61**	1.04
	12–15 years	465	*(429)*	28	*(72)*	*Z* = 3.06**	1.42
	16–19 years	406	*(790)*	6	*(23)*	*Z* = 2.67**	0.72
	20–23 years	9	*(26)*	4	*(18)*	*Z* = 0.54^{ns}	0.19
Before start athletics practice (hours)		468	*(579)*	77	*(174)*	*Z* = 2.02*	0.91
Non-organised (hours)	−11 years	17	*(34)*	53	*(118)*	*Z* = 0.95^{ns}	0.42
	12–15 years	38	*(85)*	58	*(131)*	*Z* = 0.51^{ns}	0.18
	16–19 years	11	*(32)*	40	*(90)*	*Z* = 1.51^{ns}	0.42
	20–23 years	0	*(0)*	78	*(196)*	*Z* = 1.63^{ns}	0.57

Mean *(±SD)* values. * $p < 0.05$, ** $p < 0.01$, ^{ns} not significant ($p > 0.05$); *d*: Cohen's *d*.

enlarged the strong responders' potential for long-term performance improvement into adulthood, and so facilitated juvenile talent development.

The finding is fully consistent with the hypotheses of *"multiple sampling and functional matching"* and of *"learning transfer as preparation for future learning"* in the context of nomological validation. Strong responders were more likely to experience practice and competitions in other sports before entering athletics and they continued them in parallel with athletics over multiple years, in many cases competing at a comparable level. Rather than "putting all eggs in one basket" from the outset, their participation pattern implied that they opened various career options, furthered them simultaneously over multiple years and kept them open for a relatively long time. The *election* of the main sport emerged from athletes' own experiences of various sports and thereby multiplied the probability of electing the sport of individual "best fit". The "fit" may relate to performance development per se (presumably genetically moderated), coach-athlete and peer relations, health, enjoyment, and perhaps other aspects. "Sampling" may be constrained by available opportunities, individual preferences and genetic endowment (gene-environment-interaction, Tucker-Drob, 2017). Remarkably, selection of the main sport emerged *a posteriori* and not by *a priori* assignment.

Experience in multisport practice and competitions also facilitated long-term *performance development* within track and field athletics. It led to greater (later) *practice efficacy* in athletics in that equivalent practice time elicited greater performance enhancement, and greater *sustainability* in that athletes continued to improve performance until a later age. Results of a prospective two-year quasi-experimental study (Güllich, Kovar, Zart, & Reimann, 2017) suggested that these lagged effects were accounted for by improved *motor learning*, and not by improved physical capacities (speed, power, endurance).

The young athlete acquires a wider and more "finely-grained" performance space of perceptual-motor skills that facilitates the emergence of functional *performance solutions* (i.e., athlete-functional task-athlete-environment relationships, Araújo et al., 2010; Davids et al., 2017) and also provides a broadened basis for subsequent learning. Perhaps more significantly, strong responders experienced different sport-specific "practice cultures" involving varied practice designs, learning modes, situations, settings, coach-athlete and peer interactions in learning. The experience of more varied *acquisition processes* may facilitate learning transfer and the emergence of functional *learning solutions* in future long-term learning (Bransford & Schwartz, 1999), presumably emerging from an interplay of learning and within-athlete selection processes. Varying practice designs increase the chance to encounter the most functional individual learning modes (Güllich, 2017). The diversified learning experiences also provide opportunities to differentiate which learning modes are individually more or less functional and to understand the "laws" that organise individual information-action-learning relationships (Bransford et al., 2000). Furthermore, varying task and environmental constraints provide opportunities to adjust intentions, perceptual and motor actions to different sets of information, facilitating the adaptation of the task-athlete-environment "fit" in learning (Davids, Araújo, Hristovski, Passos, & Chow, 2012). *Contrastive* learning experiences, in particular, facilitate the recognition and utilisation of more, and more varied relevant information for learning ("affordances", Davids et al., 2017). In summary, this may lead to more adaptive, "smart learners" who possess an enhanced potential for future long-term motor learning and skill refinement.

Finally, not any kind of variable sport experience is necessarily conducive. Only organised, coach-led practice and competitions in other sports, in contrast to non-organised sporting involvement, contributed beneficial effects to later performance development. That is, strong responders' engagement in other sports involved primarily *authentic* experiences that implied multi-year *dedicated, performance-oriented* practice and competition processes under the supervision of specialist coaches. The finding suggests an additional hypothesis to those discussed above – the hypothesis of *"authenticity of variable learning experiences"*.

Methodological considerations and future directions

The study was not without limitations. Although reliable and valid, the survey's retrospective design implies potential constraints in power (selection effects, possible recall bias, and limited control of error variance; Ackerman, 2014; Côté, Ericsson, & Law, 2005) and the findings are observational, not causal. In addition, the relatedness between combined sports was not explicitly tested. Virtually all sports include some "athletics" (running, jumping and throwing), and moreover, strong and weak responders did not differ in the types of sports in which they engaged. Furthermore, the study recorded "only" defined activity types while potential variation between strong and weak responders in the "micro-structure" and "quality" of practice in athletics and other sports, genotype, psychological characteristics, and perhaps others were not considered. Finally, the study focused on a highly select sample of exceptional performers. As such, the findings may not extend to lower performance levels.

An appropriate framework for future research should envisage the *interplay* between sport-*specific* and *non-specific* practice. This necessitates longitudinal studies spanning at least two multi-year periods, preferably conducted in a multi-cohort design. In this, the concrete motor actions performed in sport-specific and non-specific practice and their physical and psycho-social properties could be recorded in more detail. These investigations will help researchers better understand *how* learning transfer facilitates future learning across development.

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