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Sprint performance of male track athletes at Paralympic Games between 1992 and 2016

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Abstract

Introduction: This study sought to analyze performance progression in track and field sprint events (100–400 m) at Paralympic Games (PG) held between 1992 and 2016 and to make comparisons with Olympic athletes.

Materials and methods: Of 19 sport classes, five were selected in which the ratio of world records (WRs) set by Paralympic athletes to WRs set by Olympic athletes was the highest (T13 – visual impairments, T38 – coordination impairments, T46/47 – upper limb deficiencies, T42 and T44 – amputations and with lower limb deficiencies, T54 – wheelchair users). Percentage indices, PG/OG performance ratio as well as competition density were used to assess changes in performance. Linear regression was applied to predict performance at 2021 PG.

Results: In the period from 1992 to 2016, PG finalists improved their results by 5 to 22% in all the classes, while OG finalists improved their performance by 1 to 2%. PG/OG performance ratio depended on the class and sprint distance. The highest ratio was noted in the case of T44 (0.92 for 200 m) and T54 (0.93 for 400 m).

Conclusions: The prediction showed the highest values of the coefficient of determination (R2 > 70%) in T38 and T44 in 100 m and T38 in 200 m. The data obtained from the prediction may determine coaches' activities in terms of assessing an athlete's chances of qualifying for 2021 PG finals.

Keywords: classification, technology, Paralympic, performance trends

Introduction

In track and field and Olympic swimming, there is a long tradition of collecting and processing results as well as describing their progression [1,2]. Currently, advanced mathematical models are used to predict performance in the forthcoming and subsequent Olympic Games [3,4]. Such predictions are useful when selecting athletes likely to achieve an expected level as well as planning their training process. Long-term analyses that focus on changes in performance make it possible to discover their course and patterns. Universal laws refer to the logistic S-curve, according to which an improvement in performance occurs unsteadily, i.e., at first, the improvement rate is higher and higher (stage 1), afterward, it is steady (stage 2), and finally, it is lower and lower (stage 3) [5]. At each stage, facilitating factors (e.g., development of training methods and sports techniques, improvement in sports equipment, popularization of sport, development of scientific research) and hampering factors (e.g., psychomotor skills, sports rules and regulations) can be noted. In Paralympic sport, there is a scarcity of such research. A lot of studies used sports results mainly to evaluate classification systems [6] e.g., in swimming [7–9], track and field running events [10,11] and technical events [12]. It was revealed that in wheelchair sprints in the years 1988–1996, the greatest improvement in 100 m and 200 m performance resulted from changes in the classification, namely the reduction in sport classes (from 7 in 1988 to 4 in 1996) [11]. On the basis of the results from 1996 PG, Wu Scheng, & Williams [9] confirmed that, in terms of competition, the system of classification in swimming is effective.

When looking for predictors of performance of the best sprinters with visual impairments, a correlation was revealed between their performance (seven competitions in a year) and vertical jump test results (100 m and 200 m performance improved by 0.9% and 1.43%, respectively) [13]. Fulton et al. [9] initiated research on performance variability in swimming. They revealed that between 2004 and 2006, Paralympic swimmers exhibited improvement by 0.5% per year in 100 m freestyle event in classes S1-S13.

In long-term studies, scientists began to analyze changes in track and field performance of Paralympic sprinters and to compare it with results of Olympic athletes [14]. Greater performance increases were noted in Paralympic sprinters. Between 1992 and 2012, the greatest improvements in sprint performance were seen in classes T42 and T44 (lower limb amputations), i.e., by 26% and 14%, respectively, whereas in the remaining classes, an increase by over 10% was noted. For comparison, an improvement by 3% was observed in Olympic sprints. It is in line with the findings of Hopkins [15], who noted that Olympic runners (including sprinters) manifested a significant performance enhancement by 0.3–0.5% per year. In their research, Grobler, Ferreira, & Terblanche [14] found greater performance improvements in classes T42 and T44 compared to results obtained in other classes. They noted that it might stem from the fact of using running-specific prostheses (RSPs). It is worth continuing the course of research of Grobler, Ferreira, & Terblanche [14] due to higher and higher sports levels and greater demands associated with winning medals.

Therefore, this study sought to analyze performance improvement in track and field sprint events (100–400 m, winners and finalists) in selected classes at Paralympic Games held between 1992 and 2016 and to make comparisons with Olympic. Over a long period of time (28 years, 7 PG), clearly visible changes have occurred in disability sport, its range, technology of sports equipment and knowledge about training for persons with disabilities, etc.

Materials and methods

Sports results were extracted from the official websites of the International Paralympic Comittee (IPC) (www.paralympic.org, June 28th, 2017) and the International Olympic Comittee (IOC) (www.olympic.org, June 28th, 2017). The data cover the period from 1992 to 2016. Official results obtained by male track athletes in PG and OG finals in 100, 200 and 400 m races were analyzed. Non-probability sampling was applied taking into account the highest values of the ratio of world records (WRs) set by Paralympic athletes to WRs set by Olympic athletes:

$$\text{Ratio} = t_p/t_o,$$

where t_p – the race time in Paralympic Games or world record; t_o – the race time in Olympic Games or world record.

The higher the value of the ratio, the smaller the differences in performance between disabled and able-bodied athletes.

In 100–400 m sprints, of the 19 sport classes officially recognized by IPC, five classes representing all types of disabilities were selected for analysis (these classes are marked with arrows in figure 1):

(a) athletes moving in an upright position without assistive technology:
- class T13 – persons with visual impairments
- class T38 – persons with coordination impairments (hypertonia, ataxia and athetosis)
- class T46/47 – persons with upper limb deficiencies

(b) athletes using prostheses and athletes with lower limb deficiencies
- class T42 – persons after amputations and persons with deficiencies above the knee
- class T44 – persons after amputations and persons with deficiencies below the knee

(c) athletes moving in a sitting position:
- class T54 – wheelchair users

In class T42, athletes achieved worse results, yet the class was excluded from the analysis due to a spectacular use of prostheses and a possibility of assessing the effects of modern technology on performance. Classes T44 and T43 were joined together and, consequently, they were treated as one class in the analysis.

Performance of PG winners and finalists was analysed and compared with the results in analogous athletic events at OG during the same period of time (1992–2016). To assess performance levels and changes over time, the ratio in para-athletes' classes as well as changes in Olympic athletes' performance were investigated.

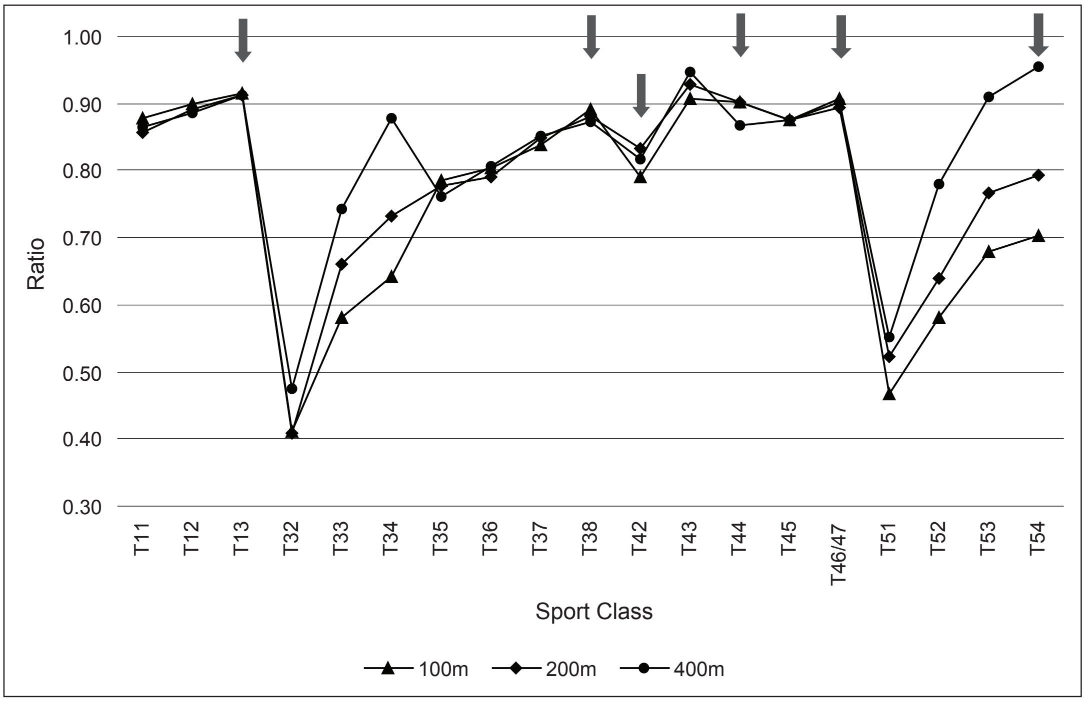

Fig. 1. The ratio of world records (WRs) set by Paralympic athletes to WRs set by Olympic athletes in 100–400 m runs

Competition density (CD) was another indicator used for performance assessment. CD was calculated according to the following formula [14]:

$$CD = [n_{finish}/(t_{last} - t_{first})]$$

CD – Competition Density; n_{finish} – number of athletes who completed the race; t_{last} – the race time for the last athlete; t_{first} – the race time for the winner.

Higher values of CD point to smaller differences between finalists in a given event.

The results obtained by finalists at 1992–2016 PG served as the basis for making predictions concerning 2021 PG. One of the statistical modeling techniques applied in the study was the simple regression analysis. It enabled us to describe the effects of time (24 years, PG) on performance. The models of the simple regression analysis allowed us to a) assess time-related effects, b) predict performance in the context of time, c) determine the size of effects of time on athletes' performance.

Linear regression took the following form:

$$Y = \beta_0 + \beta_1 * \chi + \varsigma,$$

where: Y – performance (sports result); β_0 – intercept; β_1 – regression coefficients (simple regression slope coefficients); χ – time (years); ς – random component.

The coefficient of determination (R^2) was used to assess model fitting to empirical data (performance and time). R^2 coefficient is a measure of a degree to which the model explains changes in performance over time.

Results

Performance of winners at 2016 PG in almost all the classes and races was better compared to the results achieved at PG held in 1992. The greatest improvement in performance among the winners was noted in classes T44 in 400 m race (by 21.5%) and T38 in 100 m and 400 m races (by 11.17% and 10.3%, respectively). The highest values of the ratio in 100 m sprint were noted among winners in class T13, T38, T44 and T46/47. As for finalists, the values of the ratio >0.9 were found in classes T13 and T46/47 only. In 200 m sprint, the highest values of PG/OG performance ratio both for winners and finalists were observed in class T44. In 400 m race, the highest values of the ratio both for winners and finalists were noted in class T13, T44 and T54. Over the period of 28 years, the greatest performance improvement was noted in class T44 in all sprints, both among winners (by 7% to 21.5%) and finalists (by 13.1% to 20.7%) (tab. 1).

In 100 m sprint, competition density at OG exceeded the value of 30, while at PG it came to approx. 15. The longer the distance, the lower the competition density both in Paralympic and Olympic athletes. The highest increase in competition density in 100 m race was noted in classes T44 and T42 as well as in class T46/47.

In 200 m and 400 m sprints, competition density decreased considerably. In 200 m sprint, the highest increasing trend observed in class T13 was comparable

Tab. 1. Differences in performance of winners and finalists as well as PG/OG performance ratio in sport classes in sprints

Sport classes	100% 1992 PG				PG/OG performance ratio					
	1st place		1st–8th places		1st place			1st–8th places		
	2004	2016	2004	2016	1992	2004	2016	1992	2004	2016
100 m										
T13	2.92	5.92	4.04	6.40	0.88	0.90	0.92	0.86	0.88	0.91
T38	5.96	11.17	7.43	11.44	0.82	0.87	0.91	0.79	0.84	0.88
T42	–2.29	–0.25	10.52	19.55	0.81	0.79	0.80	0.65	0.71	0.79
T44	4.73	7.05	8.51	13.13	0.86	0.89	0.91	0.79	0.85	0.89
T46/47	–2.61	1.40	3.04	5.26	0.93	0.90	0.93	0.87	0.88	0.91
T54	3.27	5.25	3.59	5.56	0.68	0.69	0.71	0.67	0.68	0.69
OA	1.10	1.51	1.70	1.57	1.00	1.00	1.00	1.00	1.00	1.00
200 m										
T13	1.56	3.60	2.62	5.58	0.88	0.87	0.89	0.87	0.87	0.90
T38	5.21		7.40		0.84	0.86		0.81	0.85	
T42	–5.48	5.76	15.15	22.29	0.82	0.76	0.85	0.64	0.74	0.81
T44	4.77	8.71	12.92	17.80	0.88	0.90	0.94	0.78	0.87	0.92
T46/47	–2.66		2.26		0.93	0.88		0.88	0.88	
T54	3.96				0.78	0.78		0.75	0.78	
OA	2.89	2.94	2.26	2.33	1.00	1.00	1.00	1.00	1.00	1.00
400 m										
T13	–0.04	5.25	0.86	11.97	0.87	0.88	0.91	0.80	0.81	0.90
T38	6.76	10.30	8.58	10.13	0.79	0.86	0.87	0.76	0.84	0.84
T44	12.93	21.50	12.60	20.68	0.74	0.86	0.93	0.72	0.83	0.90
T46/47	2.65	1.99	2.94	5.97	0.87	0.91	0.88	0.85	0.88	0.89
T54	4.83	6.44	6.31	8.35	0.87	0.93	0.92	0.86	0.92	0.93
OA	–1.15	1.08	–0.44	0.96	1.00	1.00	1.00	1.00	1.00	1.00

OG – Olympic Games, PG – Paralympic Games, OA – Olympic athletes, PG/OG performance ratio – for winners and finalists.

to Olympic athletes (10.87 and 12.31, respectively). In 400 m race, the highest value of competition density was found in class T54 (7.69), which was higher than in Olympic athletes (5.06) (tab. 2).

The prediction of performance of 2021 PG winners and finalists was the last element of assessment. In the context of athletes' performance at 2016 PG, it is predicted that they will improve their results in all the classes and sprints (tab. 3).

Statistical value of F and a corresponding probability level p confirm a significant linear correlation across all events and classes in which potential finalists of 2021 PG will compete. The highest values of the coefficient of determination (R^2) were found in classes T38 and T44 (71%) in 100 m race and in T38 (74%) in 200 m race (tab. 3). It indicates that the model of linear regression accounts for over 70% of changes in performance occurring in the course of time.

Discussion

Between 1992 and 2016, both winners and finalists improved their performance in sprints (100 m-400 m)

Tab. 2. Competition density in sprint events at the Olympic and Paralympic Games in 1992, 2004 and 2016 (in %)

Event	Games	Sport classes						
		T13	T38	T42	T44	T46/47	T54	OA
100 m	1992	9.76	5.6	1.49	4.42	5.97	10.81	26.67
	2004	17.07	8.08	1.48	5.33	9.37	9.2	28
	2016	9.46	6.48	13.56	15.38	11.43	9.88	32
200 m	1992	3.7	3.48	0.43	1.42	3.04	3.77	10.29
	2004	5.38	5.23	3.41	4.21	6.06	6.78	8.24
	2016	10.87		2.43	2.72			12.31
400 m	1992	0.31	1.05		0.94	1.48	1.83	4.76
	2004	0.3	1.62		1.85	1.58	4.12	5.16
	2016	2.18	1.43		0.76	4.69	7.69	5.06

OA – Olympic athletes.

Tab. 3. Prediction of performance in men's sprints at 2021 PG in selected sport classes – potential winners and finalists

Class	2016 PG 1st place	2016 PG avr_final	Prediction	–95.0%CI	+95.0%CI	R^2	F(1, 5)	p
				100 m				
T13	10.64	10.96	10.81	10.68	10.94	0.67	88.56	0.0000
T38	10.74	11.29	10.90	10.66	11.14	0.71	105.10	0.0000
T42	12.26	12.55	11.78	11.12	12.43	0.57	57.10	0.0000
T44	10.81	11.11	10.69	10.42	10.96	0.71	115.12	0.0000
T46/47	10.57	10.98	11.06	10.88	11.23	0.29	17.79	0.0001
T54	13.90	14.31	14.12	13.94	14.29	0.56	50.56	0.0000
OA	9.81	9.94	9.83	9.75	9.90	0.49	41.91	0.0000
				200 m				
T13	22.23	22.48	21.79	21.46	22.13	0.64	73.34	0.0000
T38			21.52	20.93	22.11	0.74	105.04	0.0000
T42	23.39	24.98	23.39	21.99	24.78	0.69	72.40	0.0000
T44	21.06	21.85	21.25	20.43	22.08	0.62	74.77	0.0000
T46/47			22.08	21.65	22.51	0.32	18.01	0.0001
T54			23.79	22.98	24.59	0.65	45.51	0.0000
OA	19.78	20.13	20.02	19.86	20.18	0.25	14.16	0.0005
				400 m				
T13	47.15	48.84	48.64	47.62	49.66	0.46	36.47	0.0000
T38	49.46	52.49	51.56	49.49	53.63	0.27	15.31	0.0003
T42								
T44	46.20	49.78	49.57	47.30	51.84	0.33	20.03	0.0001
T46/47	48.79	49.22	48.81	46.75	50.87	0.22	11.59	0.0015
T54	46.65	47.25	46.23	45.43	47.04	0.60	57.91	0.0000
OA	43.03	44.04	44.57	44.31	44.84	0.03	1.51	0.2259

PG – Paralympic Games, OG – Olympic Games, CI – confidence interval, OA – Olympic athletes.

in all the classes with the exception of class T42 in 100 m race winners and class T46/47 in 100 m and 400 m race winners. When analyzing changes in performance of Paralympic swimmers in the finals of major competitions between 2004 and 2006, Fulton et. al. [8] pointed to greater performance variability that stemmed, inter alia, from slower evolution of Paralympic sport. This standpoint may also be related to performance changes in track and field running events. Professional preparation of athletes as well as ongoing changes in prosthetic technology and wheelchair construction confirm their considerable effects on the level of performance [16,17]. The best results (world records) can be noted in classes where technologies are used, i.e., in 100-400 m sprints in class T44 (prostheses) and in 400 m run in class T54 (wheelchairs).

The highest values of PG/OG performance ratio formed the basis for implementing the non-probability sampling when selecting classes for analysis. The performance in those classes reflected a high level of functional capacity (T13, T38, T46/47) as well as a high level of functional capacity combined with the use of assistive technology (T42, T44 – runners with, T54). High values of PG/OG performance ratio (winners and finalists of PG in 1992, 2004 and 2016) were noted in athletes with visual impairments (T13) and upper limb amputations (T46/47) in 100 m and 200 m sprints. It means that athletes representing these classes achieve results that are the most similar to the ones obtained by able-bodied individuals.

The effects of technology applied in disability sport can be observed in athletes in class T54. In 400 m race, the ratio was the highest of all the classes (0.92 – 1st place and 0.93 – finalists). In contrast, the ratio was the lowest in 100 m and 200 m sprints (tab. 1). In wheelchair races, performance improvement was greater together with an increase in the distance. Similar high values of the ratio found in winners and finalists of 100 m, 200 m and 400 m races in class T44 at 2016 PG may have resulted from a wider use of specific prostheses (flex foot prostheses with high energy output during the run), especially when compared to the ratio from PG held in 1992 and 2004.

This tendency was confirmed by the findings of the studies in which technological advancement of running-specific prostheses (RSPs) was reported to be crucial in terms of improvement in 100 m and 200 m races in athletes after amputations [14,18]. These researchers also revealed the greatest performance improvement in class T42 as well as greater performance variability among finalists measured with the use of competition density. Our findings do not confirm this tendency. On the contrary, it was in classes T42 and T44 in 100 m race that competition density was the highest. It may point to the chances of winning a medal becoming more equal owing to an easier access to a wide variety of RSPs by athletes in more and more countries.

Furthermore, changes in running technique of athletes using knee and ankle prostheses (class T42) need to be emphasized. At 2012 PG, the winner's running technique differed from the technique used by other competitors. Contrary to other sprinters who had prostheses with flexible knees, this competitor used prosthetic legs without joints. The use of the 'duck-like' run resulted from looking for solutions that would optimize running technique in persons after double-leg amputations above the knee [19]. The effectiveness of this new technique led to the fact that the majority of 100 m and 200 m finalists (class T42) at PG held in 2016 used it. The application of two prosthetic legs in running revealed one more phenomenon. Namely, athletes after double-leg amputations outperformed those after single-leg amputation above the knee. It shows that the application of prosthetic legs with stiff knees enables athletes to enhance their performance as a result of better adjustment of running technique and better evaluation of its effectiveness.

Competition in class T54 looks different. In this class, para-athletes can maintain speed better than able-bodied runners as the distance of the event gets longer [20]. As far as shorter distances (100 m–400 m) are concerned, poorer performance of disabled athletes in this class compared to Olympic sprinters (the ratio of finalists between 0.69 and 0.93) may stem from the fact that it is more demanding to get started and build up speed due to lower levels of power at the beginning of the race. Moreover, in 200 m and 400 m sprints, wheelchair athletes find it harder to negotiate the bends. These observations are consistent with the findings of the current study. In 400 m run, the ratio is the highest of all the classes under investigation (0.93). In the case of longer distances (800 m or more), para-athletes' performance is better in comparison with Olympic runners. In addition, as Barrow [20] observed, wheelchair speed trends are similar in races from 800 m to the marathon; however, they are completely different from those manifested by Olympic athletes. It would be noteworthy to explain the differences in the context of psychophysical performance.

At Tokyo 2021 PG, further performance improvement in male sprints should be expected. When analyzing Paralympic swimmers' performance in the period of two years, Fulton et. al. [10] found an annual improvement to be approx. 1–2%. It means that coaches who want to increase their athletes' medal prospects substantially should aim for such enhancement. Swimming is a sport in which the use of assistive technology is forbidden. Hence, performance improvement mainly depends on training-related factors. A similar situation occurs in certain classes in track and field, e.g., T11-T13 or T35-T38, where athletes move in an upright position and the use of assistive technology is not permitted.

The results of the prediction point to big differences in sport classes. The highest values of the coefficient of determination (R^2>over 70% of concordance with the model explaining the prediction) were noted in classes T38 and T44 in 100 m run and T38 in 200 m run. The data obtained from the prediction may determine coaches' activities in terms of assessing an athlete's chances of qualifying for 2021 PG finals. For instance, the most accurate prediction ($R^2 > 0.7$) shows that to qualify for 100 m and 200 m finals in class T44, the results needed are 10.96 s and 22.08 s, respectively. In class T38, it is 11.14 s and 22.11 s, respectively. The prediction also indicates that in order to qualify for the finals at 2021 PG, athletes need to perform better than at 2016 PG.

The limitations of our analyses are mainly related to changes in the classification. Athletics is an example of changes that have happened and will continue to occur in the future. This is demonstrated by the example of classes T42 and T44, in which athletes using prostheses were excluded and new classes were created (T61-T64). The uniform Classification Code [21] introduced into the Paralympic sport system is based on scientific evidence. In the entire classification system, often very complex and highly controversial in many disciplines [16], the only assessment criterion resulting from the WHO classification is what is defined as "activity limitation". The discovery of a criterion for judging such "activity limitation" is a real challenge for the science and practice of Paralympic sport.

Another limitation is the accuracy of the forecast which depends on the number of analysed results. The inclusion of the best results for each year (e.g. by creating rankings for each competition and starting class) would increase the amount of data at least twice (by adding the results obtained in the years between Paralympics). Moreover, the extension of statistical methods with non-linear models would increase the reliability of the assessment of changes in competition results (taking into account sport classes) and also determine the stage of competition development on the 'S' logistic curve. It should be remembered that the models describing the courses of changes in results over long-term periods of time will have a different form of functions from those covering shorter periods (e.g. 4–8 years). Predictions based on shorter time frames may be more accurate, and perhaps also better explain the progressive changes primarily in hardware technology (since it is visible), as opposed to the much more difficult observation of changes in coaching athletes.

Conclusions

Between 1992 and 2016, male track athletes improved their performance in sprints at PG in all classes. PG/OG performance ratio depended on the class and sprint distance. The fact that the highest ratio was noted in all sprint events in class T44 may result from using RSPs. In class T13 and T46/47, where assistive technology is not allowed, high values of the ratio show that the level of training in athletes with disabilities (adjustment and modification of methods, forms and means used in professional Olympic sport) is getting higher and higher. Between 1992 and 2016, the greatest performance improvement was observed in classes T44 (in 200 m and 400 m runs both among winners and finalists) and T42 (in 200 m run among finalists only). The progress made in these classes may indicate how important the role of prosthetic technology development is. In class T54, the ratio increases as the distance gets longer. In this class, performance improvement will depend, among other things, on solving the problem of boosting [18]. Competition density (CD) in para-athletes in 100 m run is the highest in classes where assistive technology is used (T44 = 15 and T42 = 13). High values in class T13 may stem from better assessment of reliability and validity of classification of athletes with sensory dysfunctions, contrary to classes with motor dysfunctions, e.g., athletes with coordination impairments moving in an upright position as well as athletes with either upper or lower limb deficiencies running without assistive technology.

Compared to Olympic athletes, lower levels of competition density in Paralympic events may be associated with a smaller number of individuals who perform not only track and field sports but also other sports on a global scale.

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Conflicts of interest
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