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Original Article

New Trend for Evaluating the Technichal Performance of 4×100m Relay through Predicting the Team Targeted Record

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Abstract

Relay is an athletic event that demands a combination of physical capabilities from the athletes, as well as well-formed technical skills, especially when it comes to handing off and receiving the baton in the high-speed exchange zone. The studies, which aimed to model the relay race mathematically, have common targets to identify the optimal handing-over of the baton or locate the best position for safe baton change. Still, no study had targeted to evaluate quantitatively the performance physically and technically. The present study aims to overcome the limitation of the mentioned studies by suggesting equations that can evaluate the technical performance quantitatively of 4×100m relay performance, as a way to know the reason for the weakness, then predict the targeted team record of 4×100m relay. More importantly, the equation could be used by any coach without complicated procedures. The authors used data from world athletics website about top 4 teams of 4×100m relay, as well as non-elite groups. The supposed equations were applied. The resulted values emphasized the ability to predict the next team record as well as to evaluate quantitativly the technichal performance with details about the source of weakness for any team wether elite or not.

Keywords: *4×100m Relay, Equation, Temporl analysis, Baton Exchange*

Introduction

Relay is an athletic event that demands a combination of physical capabilities from the athletes, including absolute speed, skill speed, and endurance speed (in the case of the 4x400m relay), as well as well-formed technical skills, especially when it comes to handing off and receiving the baton in the high-speed exchange zone. The four athletes must work together harmoniously to achieve the best possible results (Podoleanu Diana, Mruţ Ivan, 2021)

The technical factor is crucial for achieving the best results in the 4x100m relay. It involves mastering the speed and accuracy of handing off and receiving the baton. Even minor errors in baton passing can significantly affect the overall performance or lead to team disqualification, even if the individual team members have outstanding personal records. Baton exchange in relay races is a high priority. The evidence could be clear by tracking the success of relay teams from Japan, Germany, China, Poland, and Ukraine, which have achieved high results in major competitions despite not having ranked athletes as the world's top performers. An ideal exchange technique in a 4x100m relay would produce a race time reduction of 2.5s better than the total individual time of four runners.(Podoleanu et al., 2021; Zhang,B.M., Chu, 2000)

A proficient handoff can partly compensate for a lack of speed but dropping the baton ruins chances for victory. The best example is the U.S. men's relay team which has failed 6 out of 9 times at the Olympic Games and World Championships since 2008. (Zarębska et al., 2021)

The Exchange Distance, typically 1m, is the distance between the approaching and receiving sprinter that constitutes a successful exchange. If a free distance of 1 m occurs at all three baton exchanges, then the total free distance is 3 m.(D.Murphy, 1992; Radford & Ward-Smith, 2002)

The studies, which aimed to model the relay race mathematically, have common targets to identify the optimal handing-over of the baton or locate the best position for safe baton change. Still, no study had targeted to evaluate quantitatively the performance physically and technically.

D.Murphy, 1992, began to model the relay race mathematically. The purpose was to develop and implement two mathematical models of the sprint relay race: an exponential1 and a polynomial. The exponential model proved to be a more accurate and flexible tool than the polynomial model. The software is useful for coaches to experiment with different combinations of athletes and team ordering and to determine the correct departure distances to minimize race time. Furthermore, various parameters can be tested to reduce race time without the risks associated with sprinting maximally during practice sessions.(D.Murphy, 1992)

Ward-Smith and Radford (2002) extend Murphy's study to examine additional factors such as the relationship between the overall relay time and the component 100 m times and compare computed times with measured times on the track. They also assessed the effect of running in curvature on running performance across the eight lanes of the track. They examine changing positions from which the athletes on the final three legs start running and at which the baton exchanges occur. They sought to answer the question: What is the optimum order for athletes with different 100 m performances?.

Masedu and Angelozzi present a tractable mathematical method to select the optimal combination of four athletes from a larger sample of athletes, given the information of each athlete's performance in each leg.(Masedu & Angelozzi, 2008)

The relation between running time and location of the baton exchange in the takeover zone is also analyzed in Zarębska et al (2021). Their experiment shows that the farther the baton is exchanged in the takeover zone, the shorter the time the baton spends in the takeover zone, which means a shorter total running time.

Karlsson & Lunander (2024) conducted a simulation study by using two stochastic analysis to investigate the tradeoff between the team's expected race time and their probability of being disqualified due to overrunning the takeover zone in 4x100m relay. Conditioning a low disqualification probability, the difference in expected race time is shown to be substantial between teams with different variation in distance assessment and forecasting running performance, respectively. They analyzed the race to minimize uncertainty problem, where the outgoing runner misjudges the right moment to start running in 4x100m relay. The study aimed to understand the effect of two random variables incoming runners' distance to checkmark and the daily shape of the running team.(Karlsson & Lunander, 2024)

Thus, the mentioned studies make it possible to quantify the baton exchange phase for elite athletes of the top 100m personal records. Where the coach already knows that they have technical problems. Those studies didn't predict the targeted record if the team members stuck to the models. They also didn't notify them how to guide the non-elite relay athletes. Most of them applied the models on men's relay teams and suggested further studies on women's relay Regarding the author's search, there is a study that evaluated the technical efficiency of the men's and women's 4 x 100 m relay by Gabriela & Marcelo (2023).

Gabriela & Marcelo (2023) study is based on statistical and documentary analysis of the database with the times or marks of the 21 men's 4x100m relays and 19 women's 4x100m relays, which gives us a total of 84 male youth athletes and 76 female Ecuadorian athletes. They aimed to define the technical efficiency of the men's and women's 4 x 100 m relay, they used formulas to find the difference between the sum of the four individual times and the relay time. The Technical Efficiency of the relay and the runner results from subtracting the relay competition time from the sum of the four individual records of the 100 m race. According to the result, they defined efficiency intervals by applying the percentile (P) method.(Gabriela & Marcelo, 2023)

The present study aims to overcome the limitation of the mentioned studies by suggesting equations that can evaluate the technical performance quantitatively of 4×100m relay performance, as a way to know the reason for the weakness, then predict the targeted team record of 4×100m relay. More importantly, the equation could be used by any coach without complicated procedures.

Materials and Method

Participants

The participants were the medals-holders' teams of the 4×100m men's relay race in Tokyo Olympic Games 2020, which was held from July 23 to August 8, 2021. These teams are the Italian, the Canadian, and the Chinese team respectively. The Jamaican team was also chosen as the world record holder in the 4×100m relay so far, which was achieved in the London 2012 Championships.

Table 1 The Medal-holders of 4×100m relay teams in Tokyo Olympic games 2020 and the WR holder

The team	Team members	100m Personal Record (s)	Relay competition record (s)
Italy (Gold)	Lorenzo PATTA	10.13	37.50
	Lamont Marcell JACOBS	9.80	
	Eseosa Fostine DESALU	10.38	
	Filioop TORTU	10.10	
Canada (Silver)	Aaron BROWN	10.08	37.70
	Jerome BLAKE	10.06	
	Brendon RODNEY	10.20	
	Andre DE GRASSE	9.89	
China (Pronz)	Xingqiang TANG	10.22	37.79
	Zhenye XIE	10.10	
	Bingtian SU	9.83	
	Zhiqiang WU	10.11	
Jamaica (WR)	Nesta CARTER	9.95	36.84
	Michael FRATER	9.94	
	Yohan BLAKE	9.69	
	Usain BOLT	9.63	

Non-elite participants were selected. They were 12 undergraduate students, final year, athletics major specialty, academic year 2023/2024, Faculty of Physical Education, University of Sadat City. They were divided into 3 teams based on their physical abilities according to 100m sprint test results, as shown in Table 2. This method aimes to test the importance and impact of technical performance with a lack of speed and with the advantage of speed (physical ability) as a team in a relay race. Then we recorded for each team its relay record.

Table 2 The non-elite participants 4×100m relay teams

The team		100m Personal Record (s)	Relay competition record
First Team	1	13.13	56.71s
	2	13.49	
	3	13.29	
	4	13.54	
Second Team	1	13.76	1:01.2 (61.2s)
	2	14.05	
	3	14.16	
	4	13.6	
Third Team	1	15.11	1:01.8 (61.8s)
	2	14.88	
	3	14.17	
	4	14.96	
mean		14.01	59.9
median		13.9	61.2
SD		0.67	2.78
Skewness		0.53	-1.64

According to analyzing the Olympic 100-meter sprints by Vasel (2021), which present some intermediate times of athletes in the final and semi-final in 100m sprint in Tokyo 2020, the intermediate times were 30m, 60m, and 80m which were compared to the world record. The authors used the analysis of the mentioned elite athletes to conclude the time differences between the 30-meter crouch start and fly start without reaction time average is (1.075s ±0.048).

According to the tests by Frank W.Dick (1989) we concluded the same time differences when we subtract the time of 30m fly from 30m block start time(Dick, 1989). Therefore, the authors adopted (1.1 s) to be applied in the equation for one athlete, as the first athlete starts from the block while the rest athletes exchanging the baton start flying, therefore, the value would be (3.3s).

Therefore, we suggest that the targeted 4x100m relay record could be predicted by subtracting the mentioned value (3.3s) from the sum of the four-100m personal records of the team.

$$\textit{Predicted 4x100 m relay Record} = \sum PR100m - 3.3 \text{ -------} \textit{Eq1}$$

We preferred to use the PR of the four athletes not the last three to generalize the equation, if the team according to a mathematical wants to test the validity of the practical application of

the method, the coach can specify the equation by using the PR of the last three of the relay team then add the PR of the first member before subtracting (3.3s**)**

Equations 1 hypothesizes that the technical performance is stable and takes no extra time for exchanging the baton.

$$\textbf{\textit{Relay performance Evaluation}} = \frac{\textbf{\textit{Predicted Relay Record}}}{\mathbf{4\times100}\textbf{\textit{m team Record}}} \times 100\text{----------}\textbf{\textit{Eq2}}$$

For elites or non-elites in relay races, there is a possibility to be disqualified because of the failure of baton exchange despite being well trained as a team, in addition to having models for putting 'go' marks and so on. But we assume that elites have the best physical ability as well as perfect technical performance. Thus, we will apply the equation to the best relay records cases to test the reliability and validity.

$$\textbf{\textit{Effect of Exchange on record}} = \mathbf{4}\times\mathbf{100}\textbf{\textit{m team Record}} - \textbf{\textit{Predicted}}\ \mathbf{4}\textbf{\textit{x}}\mathbf{100}\textbf{\textit{m relay Record}}\ \text{------}\textbf{\textit{Eq3}}$$

Therefore, we can make it as a percentage to see clearly the effect of the exchange process on the team record.

The main study was applied on 15th June 2023 on the first three teams in the Tokyo 2020 Olympics, then carried out the application on non-elite participants of students from the Faculty of Physical Education, University of Sadat City, 15th November 2023. Where the students competed in 100m sprint race, and after full rest time they competed in 4 x 100m relay.

Results

Each Relay team keeps training for achieving a new record, the question is: which Record are they targeting, which is the coach planning for a season long?

By applying Eq.1, we can predict the maximum record of the team, if the exchange time is minimized to 0s, at the same season and actual performance. Table 3 shows the results of applying Eq.1, where Italian team's predicted record would be (37.11 s), the Canadian team's (36.93 s), and the Chinese team's record (36.96 seconds), finally the Jamaican team's record would be (35.91 s). The resulting records would be a good guide or reference for the coach to plan the next season. (Table 3)

The result of applying Eq.2, as shown in table 4, enables us to rearrange the teams order in the Tokyo 2020 Olympics according to their performance and physical evaluation. The teams order according to the evaluation of their physical level is (the Canadian team, followed by the Chinese team, then the Italian team). After applying the performance evaluation equation, we find that the Italian team has the best evaluation rate, followed by the Canadian team, then the Chinese team. This is the exact order of the teams in the relay final, (see table 5, column 6).

Table 3. Prediction of the targeted team record of 4×100m Relay

Team	Sum of 4 Personal record of athletes in 100m (s)	The predicted Record (s)
Italian	40.41	37.11
Canadian	40.23	36.93
Chinese	40.26	36.96
Jamaican	39.21	35.91

When we get the Jamaican team engaged to the comparison, and apply the same equations, we will notice that the sum of personal records (39.21 seconds) was the best in the physically compared to the three teams. But by applying Eq.3, it was found that the performance evaluation of the Jamaican team was (97.47%), table 4, which is the lowest percentage compared the other teams. This comparison clearify the wekness point of technical performance of baton exchange between members of the Jamaican team, even though it holds the world record in the 4 x 100-meter relay. They depended on speed than the performance technique of baton exchange.

Table 4. Performance Evaluation of medal holders of 4×100m Relay in Tokyo 2020 compared to the Jamaican team the world record holder

Team	Relay team record (S)	Sum of 4 Personal record of athletes in 100m (S)	The predicted Record (S)	Baton Exchange time (S)	The lost time	Performance Evaluation
Italian	37.5	40.41 (3^{rd})	37.1(3^{rd})	0.39 (1^{st})	1.05% (1^{st})	98.80%
Canadian	37.7	40.23 (1^{st})	36.93 (1^{st})	0.77 (2^{nd})	2.08% (2^{nd})	97.95%
Chinese	37.79	40.26 (2^{nd})	36.96 (2^{nd})	0.83(3^{rd})	2.24% (3^{rd})	97.80%
Jamaica	36.84	39.21	35.91	0.93	2.58%	97.47%

In Table 4, we can see the importance of relay performance technique, presented as the percentage of time lost for each team's record. The Italian team had the lowest percentage at 1.05% for baton exchange time of 0.39 seconds. The Canadian team followed with a loss rate of 2.08%, and the Chinese team had a loss rate of 2.24% for an exchange baton time of 0.83 seconds. The Jamaican team had the highest loss rate at 2.58%.

But when we compare them according to performance evaluation, we observed that the lost time during baton exchange for the third team is (5.98 s) which presented by (10.71%),

followed by the first team (6.56 s) which presented by (13%), finally the second team (8.93s) which presented by (17%). The Sperman correlation coeeficient between the Relay teams records and the predicted records of the non-elite relay teams was (0.36), a positive correlation,

Table 5. Performance evaluation and predicted record the non-elite relay teams

Team	Relay team record (S)	Sum of 4 Personal record of athletes in 100m (S)	The predicted Record (S)	Baton Exchange time (S)	The lost time percentage	Performance Evaluation
First team	56.71s	53.45	50.15	6.56	13%	88.4%
Second team	61.2s (1:01.2)	55.57	52.27	8.93	17%	85.40%
Third team	61.8s (1:01.8)	59.12	55.82	5.98	10.71%	90.32%

The equations can assess not only the physical and technical performance of elite teams but also help us identify the strengths and weaknesses of non-elite or beginner teams. When we applied the same procedures and equations to the non-elite teams' records or test results, we found that the first team performed the best in the 100-meter sprint personal records, indicating the best physical performance. The second team performed next best, followed by the third team. However, when we compared the teams based on their technical performance evaluation results, we observed differences in their baton exchange times and the percentage of lost time. These results also helped distinguish between the second and third team despite a small-time difference in their records (about 0.6 ms). The third team had the best technical performance with an exchange baton time of 5.98 seconds and a lost time percentage of 10.71%. It was followed by the first team with an exchange baton time of 6.56 seconds and a lost time percentage of 13%. The second team ranked last, taking 8.93 seconds in exchanging the baton with a lost time percentage of 17%.

The coach can read the results clearly, where the Third team needs to improve the personal records of 100m sprint rather than working on baton exchange technique, while the first team needs to improve technique rather than speed, and the second team needs to improve both factors or abilities physical and technical. If the coach considers the records as a reference for planning the season, he will prefer the first and the second teams to the third. The equations could be good indicators for the coaches in such developed countries, or for youth or beginners following up, or as a method to collect a relay team .

Conclusion

Relay event depends on physical and technical abilities, the physical is presented in athletes' velocity while the technique is presented in baton exchange technique among the team members. Theoretically, both two abilities serve performance which leads to better records. The trainers have to elect 4 athletes with the best personal record in 100m or 200m sprint, and then he teaches and trains them the baton exchange technique. Through continuous evaluation tests, he can assess the team's performance. The authors predicted the targeted team record of the 4×100 m relay event by adding the best personal records of the 100m sprint of the 4 relay members of the season. Then subtract (3.3 s) of the sum, where this value is the difference between couch and fly start for the last three athletes of the relay team. Then we compare this sum with the best record of the relay team.

To know the effect of the performance technique, the authors formed equations 2 and 3, the equations depend on the predicted team record and the actual team record. The lost time resulting from baton exchange time and the efficiency of the performance is an accurate indication of the weak point of the team, whether it is physical or technical. Even the results of the evaluation can diagnose the weakness of elite and non-elite teams, despite the small-time differences between the teams.

The percentage of losses indicates what must be paid attention to improve the performance, as all the times for the selected sample are not distinctive. If the percentage of lost time is small, the coach must consider improving the team members' physical performance; if the percentage is large, the coach must work on the technique.

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