Original Article

Start performance and its relation to competition times in Paralympic swimmers

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ABSTRACT

The purpose of this study was to investigate the relationship between the variability of the 100m freestyle final race time to start performance in a population of Paralympic swimmers using the coefficient of variation (CV). A secondary purpose of study was to investigate the correlation between start performance and competition results in this population of athletes. A total of 321 data points were collected on start performances and 231 data points were collected from competition results. It was found that there was a within-athlete CV in final times of 2.6% and a within-athlete CV in start performances of 18.2%. These two parameters were moderately correlated having an r^2 of 0.57. The athletes improved their performances across five-consecutive seasons by 6.4%. In addition, it was found that a strong correlation existed between the 5m start time compared to the final race time in the 100m freestyle (r^2=0.78). The results showed that the variability of start performance was moderately correlated to the variability of the final times and there was a strong correlation between start performance and competition results. **Keywords:** Coefficient of variation; Paralympic sport; Swimming starts; Force measurements.

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INTRODUCTION

It is commonly understood by coaches and athletes alike that the start of a swim race is an important factor in the overall performance of a race. This topic has been given little attention in Paralympic swimming. Daly and colleagues (Daly, et al., 2001) described the ratio of different parameters like start, swimming or the turn of a swim race and demonstrated a positive relationship between the start and the swimming speed. Over all disability classes and in freestyle breaststroke and butterfly they found a correlation of .67. In freestyle, the highest correlation was found between the start speed and final time in freestyle for the disability classes S6 (.83) and S4 (.82) (Daly et al., 2001). The classification system in swimming contains 14 different disability classes. Locomotor impairments includes classes 1 (highest disability class) to 10 (lowest disability class). From class 11-13 the athletes have visual disabilities and in class 14 athletes have an intellectual disability (Dingley, Pyne, Youngson, Burkett, B., 2015).

As freestyle is the most common stroke and is the easiest to learn, it is used to make comparisons between Paralympic swimming athletes in different disability classes (Daly, 2001). Different disability classes were compared to each other, because we want to see if there a different impact on different classes. In addition to this, there is only a small amount of high-performance athletes per disability class competing for one nation, compared to abled body athletes.

In 2010, the new Omega OSB 11 starting block was approved for use in competition by the Fédération Internationale de Natation (FINA). Since then all international competitions are done with this start block. Tor, Pease & Ball (2014) showed that this block can help athletes gain an advantage in start performance time. Also, Honda, Sinclair, Mason & Pease (2010) showed that the new kick plate of the Omega starting block helped athletes increase their start performance in 5m-times. They measured significantly faster 5m ($p=0.002$) and 7.5m times ($p=0.0032$) (Honda et al., 2010). New technology in start platforms and higher training loads indicates that start and final times are still highly correlated.

Start performances are understood to be valuable indicators to overall race performance. Arellano, Brown, Cappaert & Nelson (1994) showed that there is a significant correlation between start performance expressed as 10m-time and the turn in, measured as the final 7.5m into the wall. They measured a correlation coefficient of .93 in men's and .90 in women for 100m freestyle events. Mason and Cossor (2000) also found high correlations between start performances and 50m times in their competition analysis of the Pan Pacific swimming championships (.84 for both sexes). The above studies show the importance of the starts to overall race results and thus the importance to understand the factors associated with starts. In addition to start times, force plate measurements have been used to assess performance in swimming. For example, Silveira et al. (2018) found that the block and flight time together, as well as the block time and the flight distance together, were very good predictors for the start performance. From these data, impulses were calculated under each foot as the product of horizontal force by time. This provided a measured impulse (Nm) under each foot.

A second objective of this study was to investigate the variability of start performances expressed as the within-athlete variability. The variability is expressed as the coefficient of variation (CV) and has been measured in single events for Paralympic swimmers (Daly, Djobova, S. K. Malone, Vanlandewijck, Steadward, 2003) and able-bodied swimming and other individual endurance sport (Malcata & Hopkins, 2014) previously. In high performance swimming, within- athlete variability of competition results is an important factor, where less variability was related to better performance and was a good predictor of success in the next race (Pyne, Trewin & Hopkins, 2004). A previous within-athlete comparison of the 100m freestyle event found a variation of 1.2% to 3.7% in different disability classes (Fulton, Pyne, Hopkins & Burkett, 2009). This variation is higher than in able bodied athletes. Pyne et al. (2004) found a within-athlete variability of 0.6% to 1.0% for different strokes and distances. To the authors' knowledge, this is the only investigation looking specifically into the within-athlete variability in different disability classes for more than one competition in Paralympic swimming.

Because these investigations showed that a low variability is a good predictor for success in swimming and the huge impact on the start performance, it is interesting to investigate how the variability of the swimming start interacts with the overall variability of a race. Start performances in swimming are so important to the overall performance and can be easily measured, this investigation can provide additional information on the variability. To the knowledge of the authors, there are no published investigations examining variability in swimming start performance and variability's relationship to overall performance of Paralympic athletes. Therefore, the purpose of this investigation was twofold. First, to investigate if there is a correlation between variation in start performance and variation in the overall performance of Paralympic swimmers. Second, it was hypothesized that the horizontal impulse, which is related to the final horizontal velocity of the athlete, will be related to a better start performance, and to overall performance.

MATERIALS AND METHODS

Participants and Measures

Eleven Paralympic athletes participated in this study from 2010-2014. Seven female and four male athletes with disability rankings ranging from S6-S10 participated (see Table 1).

Every 100m freestyle long course competition result over the five consecutive seasons were sourced from the public domain *SWIMRANKINGS* (www.swimrankings.net). Split time data was not available at every competition over the study period. In total, we sourced 231 data points from competition data. Additionally, 321 data points from start analysis during 2010-2014 were collected.

Table 1. Overview of the participants and their disability class

Disabled class	Female athletes	Male athletes
S6	1	0
S7	2	0
S8	2	1
S9	1	0
S10	1	2
S13	0	1

Procedures

In order to asses start performances, force and video data were collected on all 11 athletes during various training sessions by the authors. Pasco force plates sampling at 1000Hz (PS-2142, Pasco Scientific Inc., USA) were mounted to a start block and used to collect vertical and horizontal forces under each individual foot as each athlete performed their start (Figure 1.) Pasco force plates were validated for use in a swimming environment, demonstrating very good measurement of horizontal impulses (Silveira, 2017).

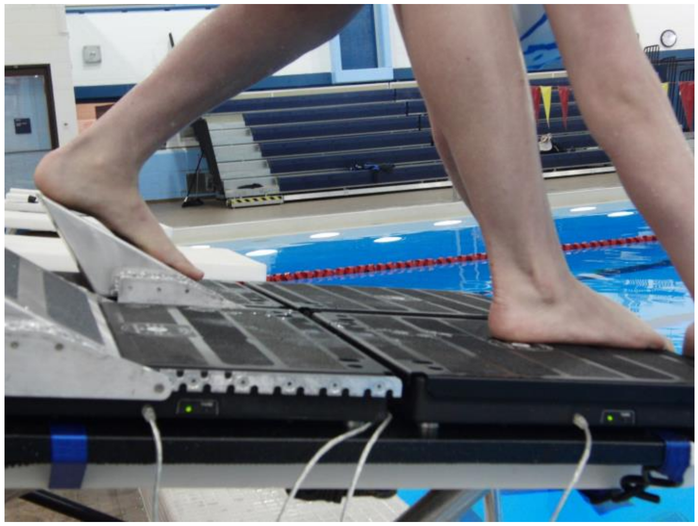

Figure 1. Pasco Forceplate.

Additionally, video cameras collected information related to time to 5m. An over water video camera was used to determine the start, via a light flash from a start gun, and a synchronized underwater camera was used to record video and determine when the athlete crossed the 5m point in the water. The performance time was recorded from the video cameras.

This study was approved by the ethics committee of the Faculty of Kinesiology at the University of Calgary and was conducted in accordance to the standards set by the Declaration of Helsinki.

Analysis

Variability of performance was calculated using the CV. The CV was calculated as the standard deviation of performance time, represented as a percentage of the mean performance time (Trewin, Hopkins & Pyne, 2004). We measured three different CVs on individual athletes:

- CV_{final} = CV of total swimming time per season (%)
- CV_{split} = CV of the 50m split time per season (%)
- CV_{T5} = CV of the 5m time per season (%)

To obtain the most accurate CV_{final} results, we only included athletes who competed in at least five competitions per season. Only athletes with at least four split time results were included in analysis of CV_{split}. For CV_{T5} only those athletes were included with at least two start analyses in one season within a minimum of ten trials per season. In total, N=26 CV_{final}, N=10 CV_{split} and N=12 CV_{T5}. In CV_{final} and CV_{T5} we had some athletes who reached those criteria's for more than one season. In contrast in CV_{split} not all athletes had a minimum of one season reaching the criteria.

To calculate the progression from year to year, we took the fastest split time and the fastest final time in competition results per season and measured the development from year to year. In an additional measurement, we calculated the correlation between CV_{final} to CV_{T5}. For this analysis, we included only athletes with at least five competitions during one season and two performance analyses with a minimum of ten trials (N=7).

The following variables were extracted to measure the correlation between the performance analysis of the swimming start and the competition result:

- T5 = 5m start times (s)
- FT = total or final race time (s)
- ST = 50m split time (s)
- TOTimp = total horizontal impulse of force under both feet (N.s)

We calculated the r-square correlation of the following six comparisons:

- T5 to FT
- T5 to ST
- ST to FT
- TOTimp to T5
- TOTimp to ST
- TOTimp to FT

All calculations, tables and graphs were calculated by Microsoft Excel version 15.28 and R-studio version 1.0.155. To pick the right data in R-studio, we used the dplyr-package and sorted our data by the needed parameters.

RESULTS

Variation of performance and correlations

Over five consecutive seasons, the within-athlete CV_{final} was 2.6% (N=26), the within-athlete split times (CV_{split}) was 2.1% (N=10). Within-athlete start times (CV_{T5}) was 18.2% (N=12). We found a moderate correlation between CV_{final} and CV_{T5} of 0.57.

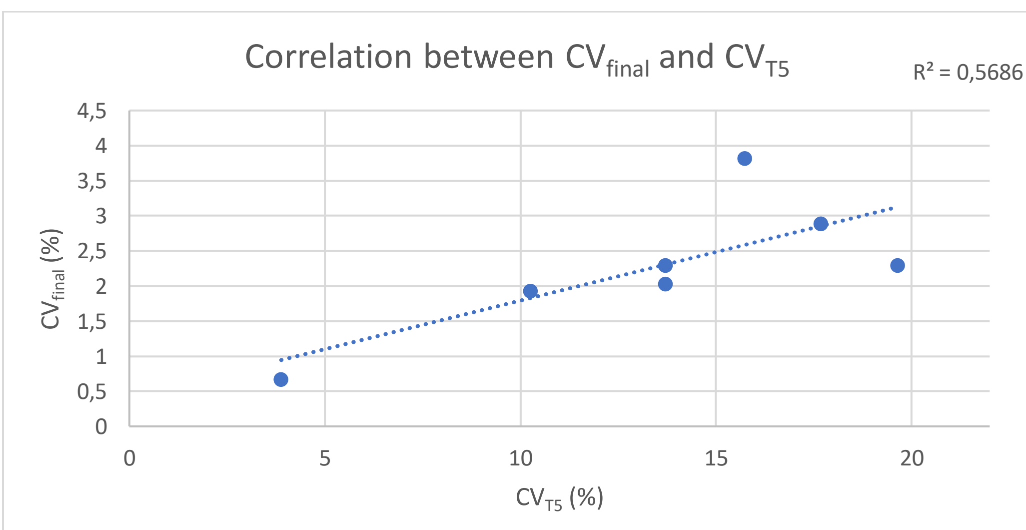

Figure 2. Scatterplot of the correlation between within-athlete CV final times and within-athlete CV 5m times for 7 objects.

Looking specifically into the different disability classes (Table 2), the S6 athlete (n=1) had a higher within-athlete CV_{final} (4.5%) than S7 athletes (3.5%, n= 2), S8 athletes (2.3%, n= 3), S9 athletes (3.3%, n= 1), S10 athletes (1.7%, n= 3) and S13 athletes (3.1%, n=1).

Table 2. Overview of within-athlete CVs in different disability classes

Disability class	Number of athletes	Within-athlete CV in one season
S6	1	4.5%
S7	2	3.5%
S8	3	2.3%
S9	1	3.3%
S10	3	1.7%
S13	1	3.1%

Correlation between start analysis and competition results

Table 3 gives an overview of all six-measured correlations. All calculated r^2 correlations were at least moderate. The highest r^2 relationship was between ST and FT (.99). Also, high r^2 values were found between T5 from a performance analysis and ST in competition (r^2=0.81), as well as in T5 from a performance analysis and FT in competition (r^2=0.78). Two other indicators were highly correlated: TOTimp measured and ST from competition data (r^2=0.70); and TOTimp and FT in competition (r^2=0.69). Lowest but still moderate correlations were measured for the performance analysis in TOTimp and T5 (r^2=0.55).

Table 3. Overview of all calculated correlations

Correlations	R^2
ST and FT	0.99
T5 and ST	0.81
T5 and FT	0.78
TI and ST	0.70
TI and FT	0.69
T5 and TI	0.55

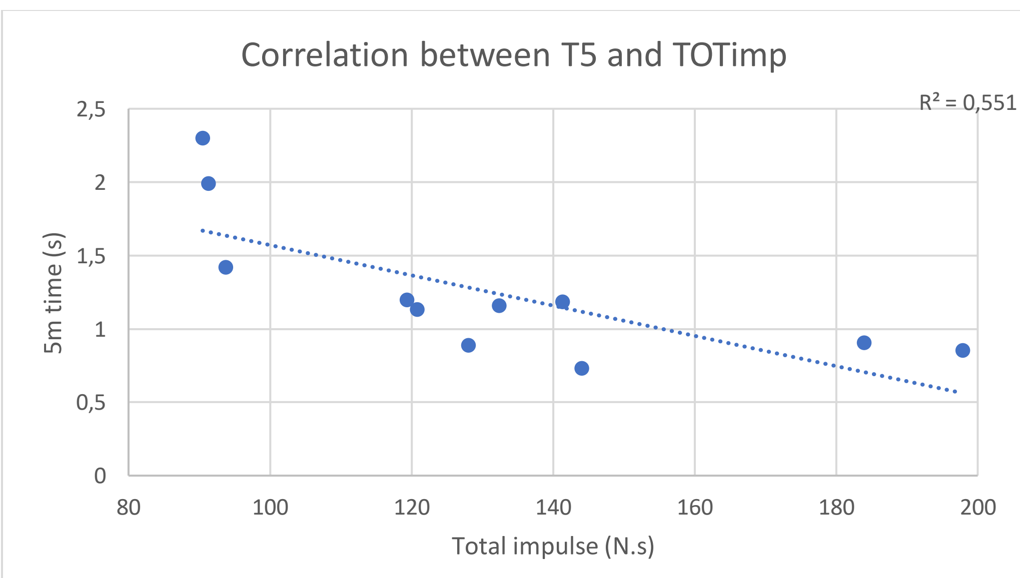

Figure 3a. Scatterplot of the correlation between the total impulse and the 5m time for 11 athletes.

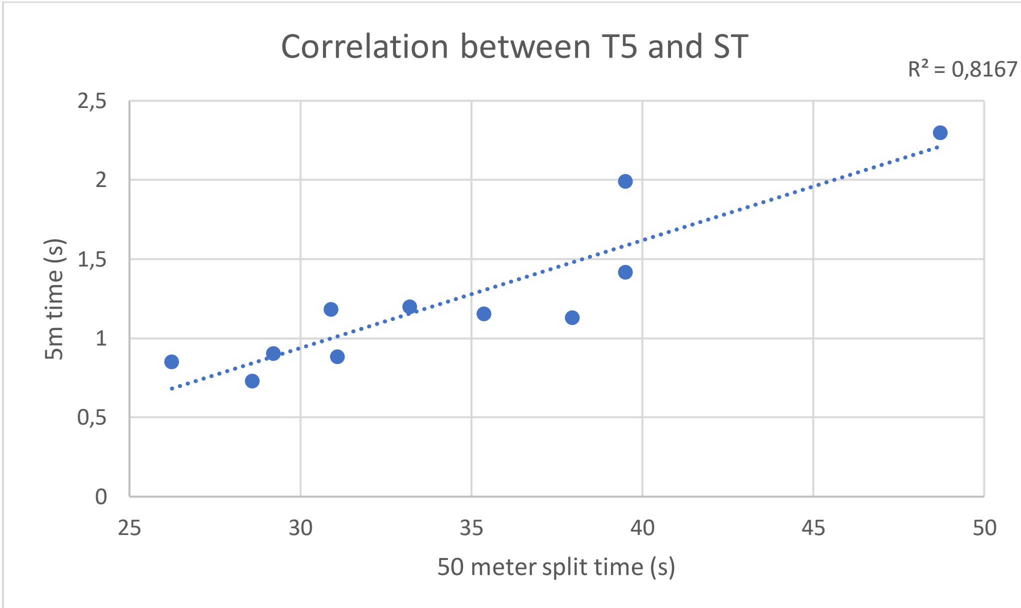

Figure 3b. Scatterplot of the correlation between the 5m time at the performance analysis and 50m split competition time for 11 athletes.

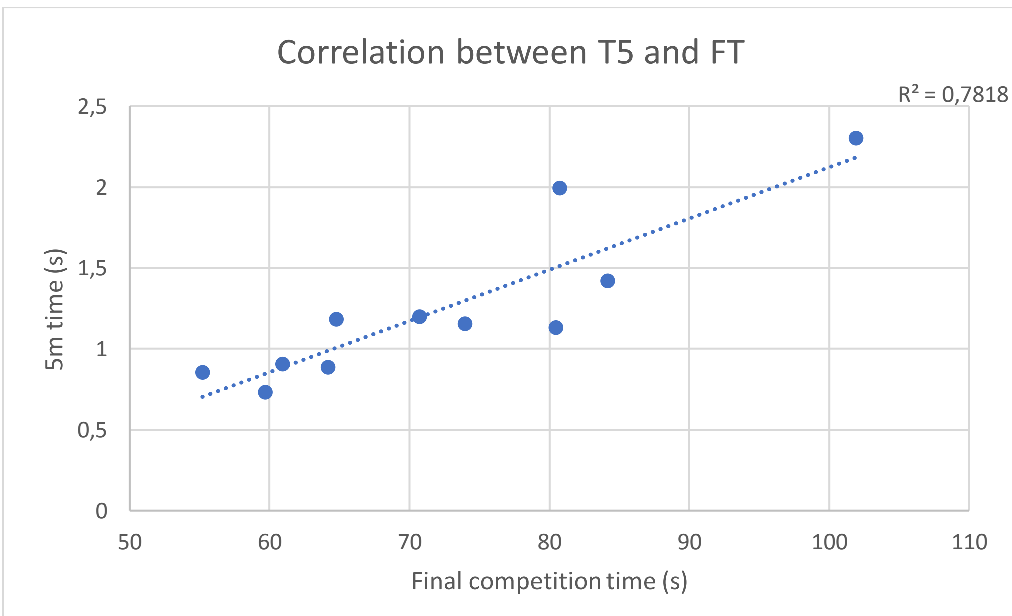

Figure 3c. Scatterplot of the correlation between the 5m time at the performance analysis and final competition time for 11 athletes.

Progression of race performances

On average, all athletes improved their final competition performance in 100m freestyle by 6.4% (+/- 6.4) over the measurement period. Split times also improved by 5.7% (+/- 6.2). Looking more specifically from season to season, it was seen that the results from 2010 to 2011 and from 2011 to 2012 increased towards the major competition, the 2012 Paralympic Games in London. The first season after the Paralympic Games split times decreased, and final results were not improved over the Paralympics year. In the 2014 season, athletes showed improvements again.

Table 4. Progression per season expressed as the best performances compared to the season before

	2010 to 2011	2011 to 2012	2012 to 2013	2013 to 2014
Split times	5.38%	0.29%	-0.53%	1.43%
Final results	3.34%	2.24%	0.12%	0.34%

In addition, the following average of competitions per athlete per season were included in analysis by year: 2010, 3.3; 2011, 5; 2012, 5.3; 2013, 3.3; and 2014, 4.5. 2012 was the year of the Paralympic Games, hence the higher number of competitions.

DISCUSSION

This investigation looked into different within-athlete CV´s and their correlation as well as the impact of the start in Paralympic swimming. The main finding is the moderate correlation between the CV_{final} and the CV_{T5} (0.57). The CV_{T5} is much bigger than the within-athlete CV in able-bodied swimmers (Trewin et al. 2004 and Pyne et al. 2004). The high CV_{T5} is possible for two reasons. First, the CV_{T5} is an interval of only a few seconds, where a bad trial in start analysis has a larger influence on variability than would a final time, which can be longer than one minute. The second reason lies in the measurement of T5. T5 measurements were done with an underwater camera at different venues. The 5m indicator was marked on the rope between the lanes, noted by a change in colour. The constant movement of the rope with the shifting water may reduce the reliability of the camera measurement. We tried to minimize the effect of rope movement by including at least ten trials for each athlete. In future investigations, it will be important to conduct all measurement at the same venue or mark the five-meter point independently from the swimming rope.

This study also showed that the within-athlete CVs of Paralympic athletes is much larger than in research related to able-bodied Olympic athletes (Pyne et al., 2004 and Trewin et al, 2004). Fewer Paralympic competitions per might be a reason for a bigger CV, because more competitions on a similar level lead to a smaller variability. In this case, a poor result may have a much higher impact on the within-athlete CV_{final} than in able-bodied swimmers who compete in many more events per year. A second interpretation of this finding could be that Olympic swimmers are more homogeneous leading to closer results and better performances in every single competition. If an athlete is not able to perform close to their personal best, he or she was not able to make the podium or at least win the race. In Paralympic swimming the gap in performance between athletes is larger and there are fewer athletes competing in each disability class, therefore, the variability of a Paralympic athlete might be larger than in able-bodied athletes.

There is also a difference between disability classes on the within-athlete CV_{final} variable. The values range from S10 (2.0% in men and 1.4% in female) to S6 (4.5% only female). Despite the typical small sample size in high performance sport, this result indicates a higher within-athlete CV from disabled class S10 to S6 leads us to speculate that the higher the disability level classification, the less consistent the results of the athlete. Fulton et al. (2009) supports our findings in their investigation using a larger sample size and fewer competition results. They merged different disability classes (S5-S7 and S8-S10) and found that female athletes had a smaller variability in disability classes S8-S10 than in S5-S7 (Fulton et al., 2009).

In another investigation, Daly et al. (2003) found that an athlete’s CV in a 100m freestyle event increased from 3.0% in S10 to 7.7% in S4. To make better interpretations on results in Paralympic swimmers, more research with bigger sample sizes need to be done. Our investigation can give a first impression on variation in start performance in Paralympic athletes.

In the present study, CV in the 100m freestyle performances increased by 6.4% over five consecutive seasons. On average, this is an increase of 1.6% per season, a result similar to previously published data (Fulton et al., 2009). A 3-4% increase over five consecutive seasons in world-ranked able-bodied swimmers has been measured elsewhere (Costa, 2010). By comparison, the improvement of Paralympic athletes in this study is more than twice that of world-ranked able-bodied swimmers.

Additionally, our study estimated that the 50m competition split times were highly related to the start performance analysis expressed as the 5m start time (r^2=0.81). Mason and Cossor (2000) found a very similar correlation (0.84) in Mason able bodies athletes. This supports the importance of the start for 50m events and the split times for longer races. In addition, Daly et al. (2001) found a strong correlation between the start and the final result in freestyle in Paralympic athletes. Our findings underline the importance of the swimming start in Paralympic athletes.

Our hypothesis that new technology would have an impact on start times was found to be incorrect.

Not surprisingly, the 50m split time and the final competition time of the 100m freestyle events are highly correlated (0.99). Because of this extreme high in race correlation, the 5m start performance analysis time is also highly correlated with the final competition time (0.78). Because the 5m time is highly correlated to the final race time, it is a very good indicator to predict a final race time of a 100m freestyle event in Paralympic swimming.

In addition, the total impulse measured at the start analysis is also correlate to the 50m competition split time as well as the final competition. Therefore, total impulse is also a good predictor for competitions results in 100m freestyle. That means, it is useful for Paralympic athletes to measure the total impulse at the start and improve this performance.

We also found a good correlation between the TOTimp and T5 (.55). Different disabilities can impact these two parameters significantly. For example, small athletes are able to generate similar impulses as taller athletes, but their 5m time will not improve so much because their body angles are worse than in taller athletes. The correlation of TOTimp to the competition results (ST and FT), as well as the correlation of the T5 to the competition results (ST and FT) show that both parameters have a big impact on performance. Therefore, start analysis in swimming are an important tool in training.

This investigation shows that research with disabled athletes of one national team is only possible with small sample sizes, because of the individual specifics of the handicap in every single athlete and the various different classifications. Because training data is not shared in international teams, this investigation is a snapshot of one successful Paralympic country. In addition, the gap between elite and sub elite athletes in one nation is huge. This makes inter-athlete comparisons very complicated. The original objective of this study to compare different CV´s from Paralympic athletes to each other. It was shown that there are large differences in CVs. Nevertheless, the within-athlete CVs in Paralympic athletes seems to be an important factor that warrants further investigation in future research.

CONCLUSION

For coaches, it is important to understand that the swimming start is an important predictor for sprint events (Mason & Cossor, 2000). The value of the CV for coaches seemed to be not as important as in abled bodied athletes, because of the lower number of competitions and the larger within-athlete CV. Nevertheless, it could be interesting to focus on that parameter if the improvement of an athlete is regressive.

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DECLARATION OF INTEREST

The authors declare no competing interests.

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