Biomechanical and comparison analysis of abled and physical disabled professional kayakers with three dimensional method on kayak simulator

PhD thesis

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1.Introduction

Flat water kayaking is an outside season sport. It is part of aquatic sports. It needs a boat, a paddle and a special technic, huge performance to keep the boat in balance on the surface of the water and go forward with. During kayaking the whole body work in a perfect harmony. The athlete use the upper limbs in a symmetrical cyclic way and doing rotational movement with the trunk, through that the lower limbs work in flexion-extension. These movements create a synchronized kinetic chain. Successful kayak paddling requires a powerful and skilful paddler with an appropriate technique to effectively maximize power to provide forward propulsion. In a case of physical disability the kinetic chain of kayaking has been change with compensating movements. Physical disability results in the whole kayaking movement and performance changes. Kayak is one of the sports suitable for physical disabled (later disabled) people. Sports can be a hobby or a professional for the disabled athlete. Para kayak is a sport recently adopted by disabled athletes, particularly its professional version all over the world. There through par kayak became a formal event at the 2016 Paralympics Games.

Through physical disability very significant differences between kayakers both in terms of techniques and performance. In disability sports a level playing field is imperative, therefore the International Para canoe Committee has created three categories for disabled athletes: Cluster1, Cluster2, and Cluster3. These categories are not in direct correlation with levels or kinds of disability; instead, they indicate what kind of movements the athletes are able to carry out. Category Cluster3 is the most active and stable group.

Keywords: kayak, par sport, biomechanics

2. Goal

Our goal was to gain more information about the kinematic, the muscle activities and force applied to the footrest of disabled kayakers. These data may indicate what kind of motions can be expected from athletes with specific injuries. The data of non-disabled athletes can serve as a starting point for the exploration of the expected movements of disabled athletes.

We have also measured additional non-disabled athletes whose movements were artificially limited to imitate disabled conditions ("imitation disabled" group).

A literature search shows that only a few references can be found about the para kayak method in the scientific literature.

The purpose of this study is to gain a reproducible method of the biomechanics of disabled person's kayaking motions and muscle activity. Ethical approval has been obtained from the Ethics Committee of Hungary 14528-1/2019/EKU. The study was carried out in a special biomechanical laboratory at the Semmelweis University Orthopaedic Clinic in Budapest, Hungary, and supported by the University of Sport Sciences and the kayak-canoe department of the Hungarian National Sport Club.

A Weba sport kayak simulator, surface myography (EMG), and a 3-dimensionalVicon (MX T40) camera system were used to record the data, and a combination Matlab and GraphPad Prism9 system was used to analyse the results. The Wilcoxon probe and Pearson correlation have been used for statistical analyse.

This specialised biomechanical method has been admitted a very effective and helpful analytical tool in this case. Our study measured the accurate force of the lower limb by use of a built-in special dynamometer (devised locally in the laboratory) in the footrest during kayaking. Data from the literature shows that the contribution of lower limbs is a crucial point in kayaking, but due to the difficulty of measurement there is no accurate force data available.

These data may indicate what kind of motions, muscle activity, force and power output can be expected from athletes with specific injuries.

Hypothesis:

1. Our basic assumption was that the injury of the trunk and lower limbs does not hinder upper limb motions and muscle activities in the case of disability. Therefore, we did not expect significant differences between upper limb activity data from non-disabled and disabled athletes.
2. We expected to find significant differences in the data describing the motions of the trunk, the lower extremities across 200 metre kayaking to be act on the utilisation to the footrest.
3. We investigated the importance and effectiveness of the footrest use. Abled athletes are able to use the footrest in contrast with disabled athletes. Therefore we expected significant differences in the force of footrest and in power output.
4. Because the lack of footrest use we hypothesised significance between the abled and disabled athletes in force applied to the footrest. We assumed significant differences both in force and power output in case of disability across kayaking.
5. Successful kayak paddling requires symmetrical movements to provide forward propulsion. Asymmetrical movements can cause less effective paddling.
   In this perspective we did an analysis of the right part and left part activity in case of abled athletes wether we found significant difference. We also observed the correlation between the utilisation of the footrest and power output across 200 metre kayaking.
6. We have also measured the healthy athletes as if they were in disabled conditions. (later „imitate” group). We hypothesised in case of imitate group we are able to produce the same biomechanical parameters such as disable group with using a special kayak seat.

3.Materials and Methods

A homogeneous group of athletes was chosen to guarantee more accurate results. All the athletes were professional male paddlers. Thirteen(n=13)elite physical disabled athletes mean age 29 (18-40) years, mean height 179 (164-194) cm, mean weight 83,5 (74-93) kg, eleven (n=11) elite non-disabled athletes mean age range: 24 (18-30) years, mean height 184,5 (172-197) cm, weight 84 (72-96) kg and nine (n=9) imitation disabled paddlers from the abled group were measured on a kayak simulator.

In the imitation disabled group, the athletes motions were artificially limited to imitate disabled conditions using special appliances.(Figure 1.)

Figure 1. Special sitting appliances for disabled kayakers.

3.1.Preparation:

Before the three-dimensional measurement the following arrangements were necessary: Anthropometric data have been recorded in the Vicon system: the length of the lower limbs (from the anterior superior iliac spine to the medial malleolus), width of the knee (from the medial side to the lateral side condyle of the tibia), width of the ankle (from the medial to the lateral side of the malleolus), distance of the shoulder and axilla(from the acromion to the axilla), the width of the elbow (from the medial to the lateral condyle of the humerus), width of the wrist (from the processus styloideus radii to the distal ulna) and the thickness of the palm (3^{rd} metacarpal joint).

3.2. Biomechanical part

This research was performed in the biomechanical laboratory of the Orthopaedic Clinic of Semmelweis University, which provided facilities and appropriate conditions for the study. Through the measurement process a Weba sport kayak simulator, surface myography (EMG FREEEMG; BTS Bioengineering), and six piece three-dimensional Vicon MX T40 camera system (Vicon Motion System, Oxford Metrics, Oxford, UK) were used to record the data. Footrest utilisation was measured with built-in dynamometer (devised locally in the laboratory MEANWELL GS18A12-P1J) in the footrest of the simulator. (Figure 2.)

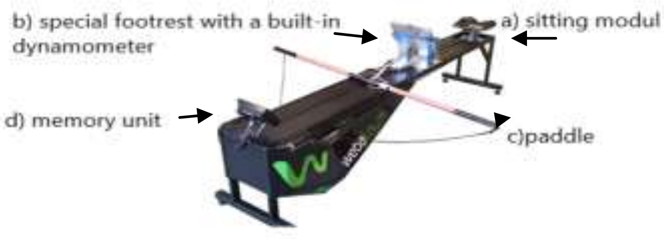

Figure 2. Kayak ergometer with a built-in dynamometer.

Light-reflecting markers were applied to the simulator and to anatomical points according to the Plug-in Gait protocol in Vicon system: acromion, suprasternal notch, distal part of sternum, upper part of humerus, lateral condyle of humerus, upper part of forearm, processus styloideus radii, distal part of ulna, 3rd metacarpal, anterior superior iliac spine, posterior superior iliac spine, upper part of femur, lateral condyle of femur, upper part of tibia, and lateral malleolus. Light reflecting markers were also have been used on the kayak simulator and the paddler. The three-dimensional camera system used these markers and anthropometric data to detect the kayakers' body. (Figure 3.)

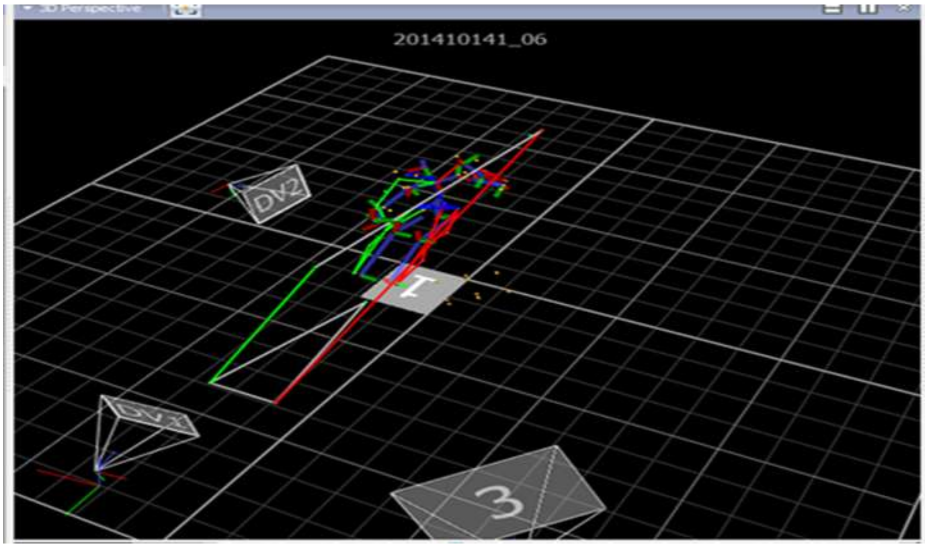

Figure 3. Three dimensional picture about kayaking.

After fixing the markers on to the anatomical points and disinfecting the skin, surface myography electrodes were applied to the middle third of most important muscles both on the left and right side: latissimus dorsi muscle, anterior deltoid muscle, pectoralis major muscle, biceps muscle of the arm, rectus femoris muscle, biceps femoris muscle, and external oblique abdominis muscle.

We used a Polar heart rate monitor to control the heart rate of the athletes during the investigation. Athletes were asked to complete a warm-up distance, then paddle a distance of 200 meters with 80% sub-maximal intensity, followed by cool down until their heart rate decreased to the prescribed range (minimum warm up heart rate, determined individually for each athlete). 200 meters is an official competition distance for both non-disabled and disabled athletes. The measurements were supervised by a physician and a coach. The force and power output like the force of the footrest and stroke length were recorded in the system of the kayak simulator. The measured data were simultaneously streamed to and registered by a central computer.

4. Results

Surface EMG was used to measure the maximum and minimum values of the most important muscles (in terms of kayaking motion), the camera system determined the maximum and minimum range of motion values of the joints, while the force applied to the footrest was measured with a built-in pressure dynamometer in the footrest. (Table 1)

Summary	**disabled athletes(SD=3,95)**		**abled athletes(SD=0,15)**	
muscle activity (V)	minimum	maximum	maximum	minimum
right musculus deltoideus	4,66	4,21	5,08	4,70
right musculus latissimus dorsi	1,76	3,015	3,60	2,17
right musculus pectoralis major	0,22	3,20	3,81	2,21
right musculus biceps brachii	4,94	4,039	6,11	5,39
right musculus obliquus externus abdominis	0,03	1,33	3,34	2,88
right musculus rectus femoris	0,03	0,07	0,72	0,50
right musculus biceps femoris	0,006	0,08	1,25	0,25
left musculus deltoideus	3,21	4,59	5,04	4,33
left musculus latissimus dorsi	2,06	3,03	3,00	2,12
left musculus pectoralis major	1,49	3,16	3,69	2,16
left musculus biceps brachii	4,451	5,52	6,03	5,73
left musculus obliquus externus abdominis	0,01	0,76	3,84	3,40
left musculus rectus femoris	0,03	0,05	0,86	0,59
left musculus biceps femoris	0,01	0,15	0,25	0,21
	disabled athletes(SD=29,05)		**abled athletes(SD=14,38)**	
range of motion of the joints (degree)	minimum	maximum	maximum	minimum
right elbow	21,14	54,60	55,10	22,49
left elbow	70,78	32,36	70,18	36,27
right shoulder	23,28	52,25	54,52	24,65
left shoulder	21,41	54,92	53,94	21,58
trunk	11,11	20,34	23,70	14,64
right knee	12,56	19,16	31,61	18,46
left knee	10,00	14,21	38,80	27,90
	disabled athletes(SD=89.30)		**abled athletes(SD=58.17)**	
	minimum	maximum	maximum	minimum
left footrest (Newton)	17,148	176,798	378,996	37,239
right footrest (Newton)	15,162	143,252	338,086	49,679

Table 1. – Maximum and minimum values of the range of motion, muscle activity and the power of the footrest across 200 metre kayaking in case of professional male kayakers.

Processing of the measurements was performed with Matlab data processing system. Statistical analysis was performed using GraphPad Prism9. Wilcoxon tests and Pearson correlation were performed to statistically analyse the data to probe whether there were significant differences between data from different kayakers. Results were obtained at 95% confidence interval level. All the measured values were analysed, differences had been found between the right and left sides in terms of range of motion in joints and the trunk motion but that were not significant $p_{elbow} = 0.2061$; $p_{knee} = 0.6377$; $p_{shoulder} = 0.4131$; $p_{trunk} = 0.1016$. (Figure 4.) Comparison of the muscle activity on the left and right side across 200m kayaking. Differences had been found between the right and left sides in the activity of the involved muscles as we hypothesized, the differences were significant except by m. deltoideus and m. pectoralis major. ($p_{latissimus} < 0.0001$; $p_{bic.brach.} = 0.0138$; $p_{obl.ext} < 0.0001$; $p_{rect.fem.} = 0.0369$; $p_{bic.fem.} = 0.0449$). (Figure 5.)

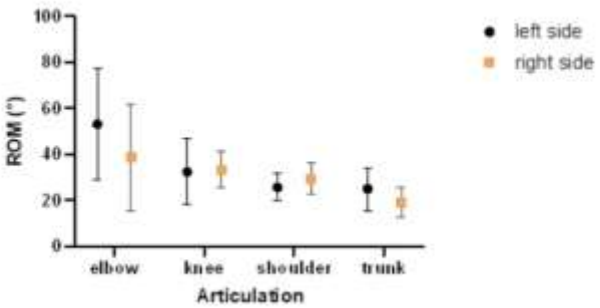

Figure 4. Comparison of the range of motion of the joints on the left and right side across 200m kayaking. All the measured values were analysed, differences had been found between the right and left sides in terms of range of motion in joints and the trunk motion but that were not significant $p_{elbow} = 0.2061$; $p_{knee} = 0.6377$; $p_{shoulder} = 0.4131$; $p_{trunk} = 0.1016$.

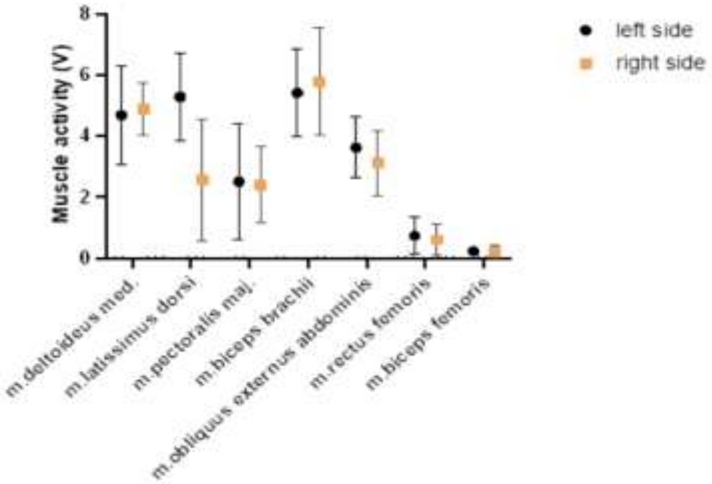

Figure 5. Comparison of the muscle activity on the left and right side across 200m kayaking. Differences had been found between the right and left sides in the activity of the involved muscles as we hypothesized, the differences were significant except by m. deltoideus and m. pectoralis major. $p_{latissimus}<0.0001$; $p_{bic.brach.}=0.0138$; $p_{obl.ext}<0.0001$; $p_{rect.fem.}=0.0369$; $p_{bic.fem.}=0.0449$.

Additional analyses showed a positive correlation between the footrest and the kayaker's power output where the correlation coefficient was 0.76 with 0.30 and 0.93 limit values. (Figure 6.) In other words, power output during the motion is affected by the force applied to the footrest, indicating a positive correlation.

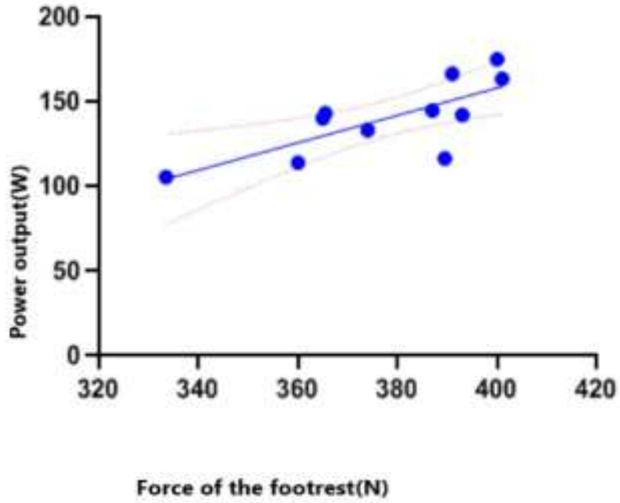

Figure 6. Correlation of performance and the footrest in 200m kayaking by professional male single kayakers where the correlation coefficient was 0.76 with 0.30 and 0.93 limit values.

More efficient utilisation of the footrest enables the kayaker to generate higher power output. Additional analyses showed a very good linear correlation between the force applied to the footrest and the kayaker’s average stroke length, the Pearson correlation coefficient was 0.33 with -0.33 and 0.77 limit values. (Figure 7.)

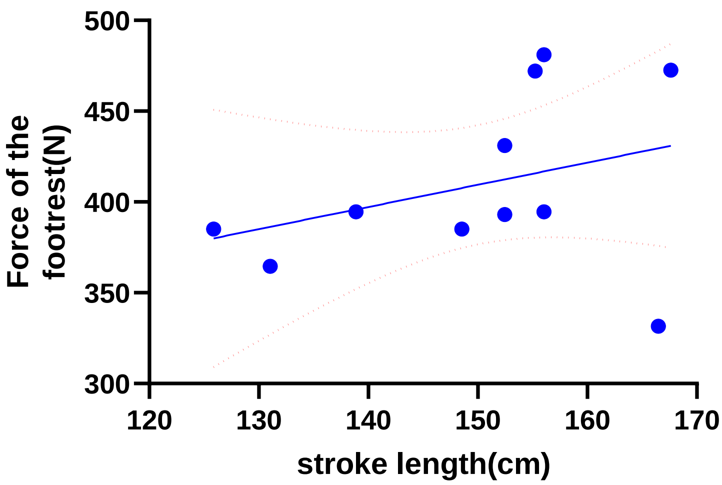

Figure 7. Correlation of the stroke length and footrest in case of professional male single kayakers in 200m kayaking. The Pearson correlation coefficient was0.33 with -0.33 and 0.77 limit values.

Correlation was also found between the stroke length and power output, with a correlation coefficient of 0.591 with -0.01 and 0.87 limit values. (Figure 8.) So the athlete has a higher power output, has a longer stroke length.

Further analysing the laterality of stroke length, significant differences between the right and left sides were observed in most cases except $p_1=0.0009$; $p_3=0.0224$; $p_4<0.0001$;$P_6=0.0016$; $p_7<0.0001$; $p_8<0.0001$; $p_9=0.0009$; $p_{10}<0.0001$; $p_{11}=0.0037$ except number 2 and 5. This is an important finding because significant asymmetry is a determining factor in strain and the risk of injury during technical training.

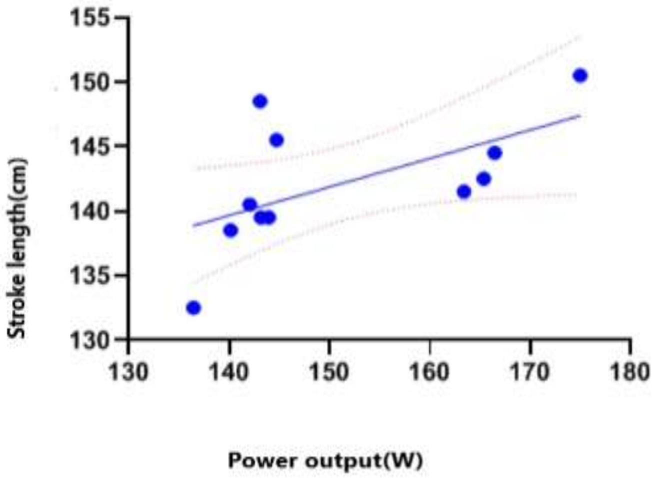

Figure 8. Correlation of the stroke length and performance in case of professional male single kayakers in 200m kayaking. The Pearson correlation coefficient was 0.591 with -0.01 and 0.87 limit values.

Footrest utilisation was measured with a built-in dynamometer (devised locally in the laboratory) in the footrest. Comparison of the footrest on the left and right side across 200 metre kayaking in case of elite male kayakers. Differences were observed in the force applied to the footrest on the right and left sides and it reached the level of statistical significance $p_{2;3;6;7;9;10}<0.0001$; $p_1=0.0063$; $p_8=0.0156$; $p_{11}=0.0225$ except in instances number 4 and 5.

The study also determined that the quality of footrest utilisation affected power output, suggesting that the monitoring or potentially the correction of differences is important. Monitoring can be accomplished by measuring the force applied to the footrest. Better and more precise utilisation of the footrest allows the use of correct technique and trunk motion in a wider range further supporting the dynamics of motion and assisting the kayaker in producing the required force output.

We expected that in the disabled group the force and the power output would decrease due to the lack of support via the footrest use. The differences in force was significant $p_{abled\ vs.\ disabled} \leq 0.0001$; $p_{abled\ vs.\ imitate} = 0.027$ and the power output was also significant ($p_{abled\ vs.\ disabled} \leq 0.0002$; $p_{abled\ vs.\ imitate} = 0.031$. (Figure 9-10.) Accordingly, we can state that our hypothesis positing that kayaking motions in disabled and non-disabled athletes are significantly different was correct. The measurements from the imitation disabled group also reinforce our results.

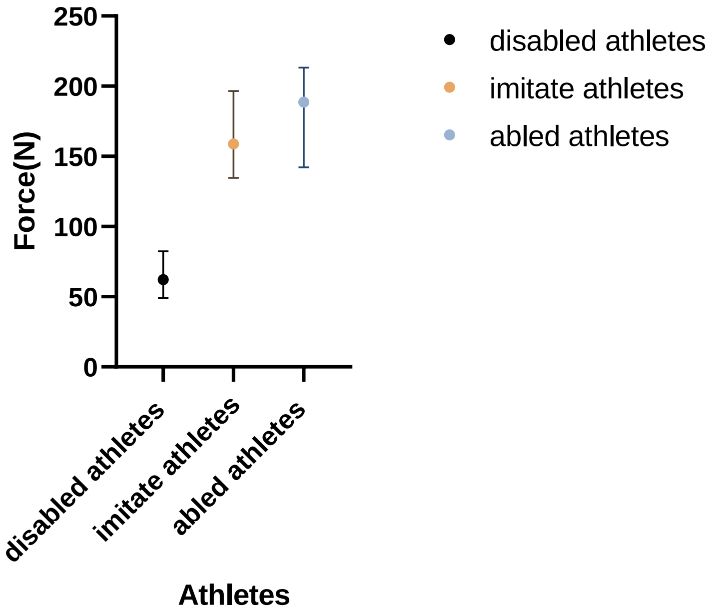

Figure 9. Comparison of the force by elite male single kayakers in 200m kayaking:

$p_{abled\ vs.\ disabled\ force} \leq 0.0001$; $p_{abled\ vs.\ imitate\ force} = 0.027$.

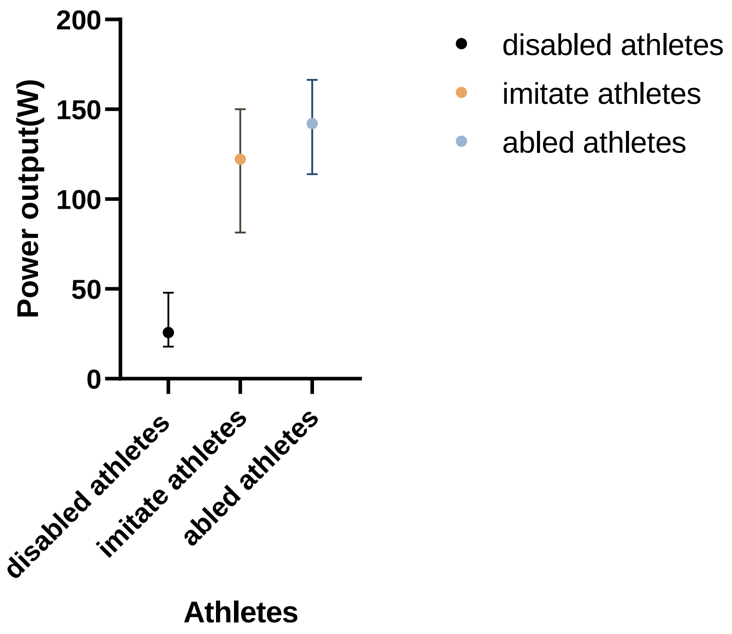

Figure 10. Comparison of the power output of elite male single kayakers in 200m kayaking: $p_{\text{abled vs. disabled power output}} \leq 0002$; $p_{\text{abled vs. imitate power output}} = 0.0313$.

5.Conclusion

Force output is very important or even the most important factor in professional sports because the athletes' results are dependent on this factor. In the course of the present study great emphasis was placed on this factor, similar to most studies in the relevant scientific literature. Biomechanical data obtained by our researchers were used to analysed the motion of professional male kayakers providing meaningful, decisive correlations and differences between motions that can be utilised by both kayakers and their coaches to improve their training design and preparation for competitive events. Similar research studies described in the scientific literature also draws attention to asymmetry during motion which is more frequently observed phenomenon in kayaking than in similar sports based on symmetrical and cyclic motions such as running and cycling.

A special feature of our study was a built-in dynamometer in the footrest. With this dynamometer the force applied to the footrest could be measured numerically.

In kayaking, non-disabled athletes are able to use the footrest fully, facilitating the correct execution of specialised technique, and they are able to output more force and longer stroke length and higher performance. In case of either symmetric or asymmetric disability, the athletes are unable to use the footrest fully, and as a consequence these athletes compensate their motions with their trunk and healthy upper limbs. These factors result significant differences in upper limb activity: joint motin, in many cases the muscle activity, in stroke length as well as lower force and power output. Although the importance of lower limbs and the footrest have already been investigated, the force applied to the footrest has never been measured in this way. Our study also demonstrated that the force applied to the footrest is also crucial in the case of disabled elite kayakers. Our study provided novel information about how an athlete compensates to be able to do kayaking with a physical disability, and we obtained new data on significant differences in motion of the joints, muscle activity, in power output and force. The study confirms that expertise may be helpful in the technical improvement of athletes, in addition to monitoring their health and resolving any possible injuries. The method give a wider opportunity to disabled athletes to compete in a professional way.

The results indicate the need for further investigations of the correlations we have uncovered, and hopefully we can learn more about the motion of disabled athletes in this sport.

Data can indicate the way to more specialised and individually tailored training methods for coaches and athletes. As para sports show a growing trend, scientific research should focus more on this area. A deeper understanding of para sports can ensure better professional training for athletes.

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