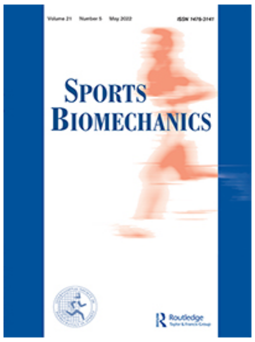

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Kinematic and kinetic performance variables during paddling among para-kayak athletes with unilateral above or below knee amputation

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ABSTRACT

In para-kayak, athletes with unilateral above knee amputation (AK) and athletes with below knee amputation (BK) compete in the same class. This has been questioned since previous research have shown that the legs are important for paddling performance. The purpose was therefore to examine differences in kinematic and kinetic performance variables between AK and BK para-kayak athletes and the amputated (A) and non-amputated (NA) sides. Eleven AK and six BK athletes on international level participated. 3D kinematic and kinetic data were collected for the body, seat, footrest and paddle during kayak ergometer paddling. There were no significant differences between the groups in main performance variables such as power output or paddle force. Differences between the groups were only seen in the hip joint in flexion range of motion, flexion and extension angular velocity and flexion moment where BK demonstrated larger values. The NA side demonstrated greater values compared to the A side in posterior force at the seat and in hip flexion moment. As there were no significant differences between the groups in the majority of the examined key performance variables, the results suggest that athletes with unilateral AK and BK amputation may be able to compete in the same class.

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Paracanoe; classification; paralympics; impairment; kayak

Introduction

The performance in time-based sports is directly related to a high average velocity. In sprint kayaking, this is achieved by the kayaker's propulsive force at the paddle blade exceeding the hydrodynamic drag force created between the water and the kayak and the aerodynamic drag force (McDonnell et al., 2013; Michael et al., 2009). Kayak propulsive force is influenced by athletes' anthropometric features as well as physiological, biomechanical and neuromuscular factors. Previous studies suggest trunk and leg movements

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during kayak paddling to be important for creating force at the paddle and thus increasing performance (Begon et al., 2010; Bjerkefors et al., 2018, 2019; Nilsson & Rosdahl, 2016). In fact, lower limbs may contribute to up to 21% of paddling force, 16% of kayak speed (Nilsson & Rosdahl, 2016), and perhaps ultimately contributing to an increase in performance by 6% (Begon et al., 2010). Moreover, it is thought that the asymmetrical leg movement helps the pelvis to rotate leading to an increased trunk rotation that allow the forces created by the leg muscles to be transformed to propulsive force at the paddle and thus have a positive impact on performance (Begon et al. 2010; Bjerkefors et al. 2018, 2019).

Five contact forces that act on the kayaker's body have been described; at the paddle (left and right hands), at the seat and at the footrest (left and right feet) (Begon et al., 2010). Some of these contact forces have been researched within able-bodied athletes using a kayak ergometer in the laboratory (Begon et al., 2010; Bjerkefors et al., 2019) and in a kayak on water (Aitken & Neal, 1992; Gomes et al., 2015; Nilsson & Rosdahl, 2016). These findings are however not directly transferable to Para athletes who compete in para-kayak events that are performed on flat-water over 200 m, since they have limb deficiencies, impaired passive range of motion (ROM) or impaired muscle power affecting the trunk and/or legs.

Few biomechanical studies are available on para-kayak athletes. Bjerkefors et al. (2019) found differences in trunk and leg movements and in power output between 41 elite para-kayak athletes that were divided into three para-kayak classification classes: Kayak Level 1 (KL1), Kayak Level 2 (KL2) or Kayak Level 3 (KL3). As expected, KL1 athletes (who have the most impairment) had less power output and leg and trunk movement compared to the athletes from KL2 and KL3 (who have the least impairment). Interestingly in the same study, KL3 athletes, who commonly have an impairment affecting only an ankle or both an ankle and a knee, did not only have significantly less hip, knee and ankle flexion ROM compared to able-bodied kayak athletes, but also significantly less trunk and pelvis rotation ROM. Furthermore, a lower power output compared to the able-bodied athletes was also seen, which suggests that a deficiency in generating leg movement affects performance. Ellis et al. (2018) examined the effect on performance of wearing or not wearing a prosthesis in a recreational kayaker with above knee amputation during a 200 m simulated kayak race on a kayak ergometer. They found that the time taken to complete the race was not significantly different between the two conditions. Interestingly, however, an increase in stroke rate, stroke speed and power output were evident when a prosthesis was not worn (Ellis et al., 2018).

The KL3 class in the para-kayak classification system, which was implemented in 2015, includes athletes with impaired passive ROM, impaired muscle power or limb deficiency which affects the legs. In this class athletes with an impairment affecting the knee and ankle or only the ankle can compete against each other. Since the leg movement during paddling is most likely a result of the flexion and extension of the knee joints, athletes and coaches have questioned whether athletes with an impairment affecting only the ankle or both the ankle and the knee should compete in the same class. The purpose of this study was therefore to examine the differences and similarities in kinematic and kinetic performance variables between para-kayak athletes with a unilateral above knee (AK) or below knee (BK) amputation during kayak ergometer paddling at a race pace intensity. An additional purpose was to, where possible, examine differences between the amputated (A) side and the non-amputated (NA) side. It was hypothesised that the AK athletes would be disadvantaged in the main performance variables such as paddling power output, paddling force or paddling velocity compared to the BK athletes and that the A side would be disadvantaged compared to the NA side.

Method

Participants

Seventeen international level competitive para-kayak athletes from 13 different countries across five continents volunteered to participate in this study. The inclusion criteria for all participants were that they were an international level competitive para-kayaker with either an unilateral AK or BK amputation. Participants were assigned to two groups; group AK, consisting of 11 athletes with unilateral AK amputation (mean ± standard deviation (SD), 9 males: 29 ± 9 years, 75 ± 11 kg, 1.78 ± .07 m and 2 females: 43 ± 5 years, 52 ± 3 kg, 1.64 ± .05 m); and group BK, consisting of 6 athletes with unilateral BK amputation (4 males: 25 ± 2 years, 81 ± 16 kg, 1.81 ± .12 m and 2 females: 30 ± 9 years, 67 ± 6 kg, 1.69 ± .06 m). The mean ±1 SD personal best times during the 2017 World Championship were 43.047 ± 2.147 s and 43.901 ± 2.787 s for the male AK and BK athletes, respectively. For the female athletes the mean ±1 SD personal best times were 51.328 ± 1.757 s for the AK athletes. Data from the female BK athletes (n = 2) cannot be presented due to that one of the athletes did not participate in the competition. During competition para-kayak athletes with amputation are allowed to paddle with or without prosthesis. Two male athletes in the AK group and all male and one female athlete in the BK group wore a prosthesis. Ethical approval for the study was granted by the Swedish Ethical Review Authority, and participants provided written informed consent and completed a health declaration form prior to participation.

Equipment

The kayak paddling was performed on a kayak ergometer (Dansprint ApS, Hvidovre, Denmark). The ergometer settings were based on the athletes' preference. The athletes were asked to replicate their normal competition and training set-up. Athletes who do not use a prosthesis during paddling generally use adaptive equipment which locks their residual limb in the kayak. Such adaptive equipment was therefore created and was used by all athletes in the AK group who did not use a prosthesis (Figure 1).

Three-dimensional kinematic data were recorded using a 12-camera optoelectronic system (Oqus4, Qualisys AB, Gothenburg, Sweden) at a sampling frequency of 150 Hz. The system was calibrated according to the manufacturer's guidelines. Between 61 and 78 reflective markers (12 mm diameter) were attached to anatomical landmarks in order to construct a whole-body model consisting of 13 to 15 segments depending on whether the athletes used their prosthesis or not. The marker placement was the same as a previous study by Rosén et al. (2019) but with additional markers; four markers on the head, one marker on each hand, two markers laterally on each side of the spine at a lumbar level and one marker on processus xiphoideus. In addition, three markers were placed on the kayak ergometer paddle shaft (without blades); one at each end and one on the middle.

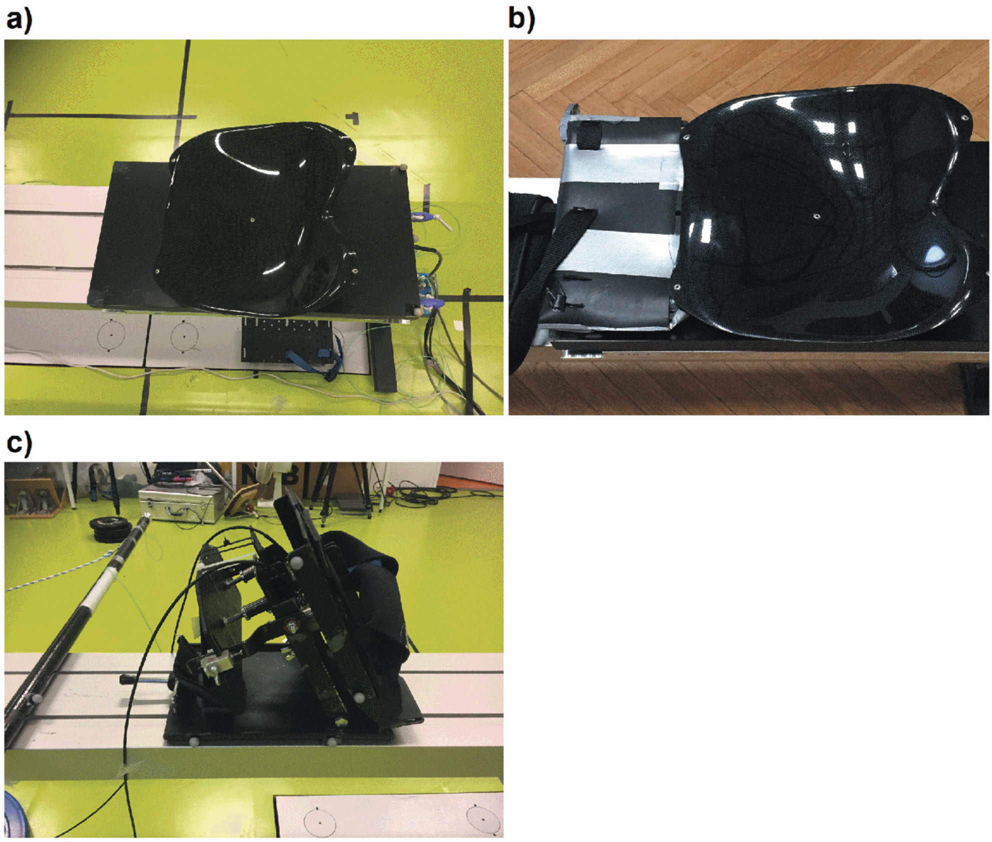

Figure 1. Pictures of seat and footrest setups. (a) the seat mounted on top of the force plate, (b) the adaptive device used by the athletes with above knee amputation, mounted on the force plate and seat, (c) the footrest where two 3D force transducers were connected.

Reflective tape was placed around the middle part of each of the force transducers attached to the paddle and two markers were attached on each side of the flywheel rotation centre in order to create virtual markers at the fixed points where the rope runs into the ergometer flywheel on each side.

Uniaxial piezoelectric force transducers (Type 9311B, Kistler Instruments AG, Winterthur, Switzerland) were attached between the ropes and at the ends of the paddle shaft to continuously measure force at the paddle. A force plate (Model 2550–06, Bertec Corporation, Columbus, Ohio, US) was attached to the ergometer with a kayak seat mounted on top in order to measure 3D forces and moments at the seat (see Figure 1). A custom made footrest was constructed with two piezoelectric force transducers (Type 9347B, Kistler Instruments AG, Winterthur, Switzerland) to measure forces in 3D at each foot (see Figure 1). All data from the force transducers and force plate were sampled at a frequency of 150 Hz. The force transducers were connected to an amplifier (Paddle: Type 5073, seat: Model 3282013, Bertec Corporation, Columbus, Ohio, US, footrest: Type 5405A; Kistler Instruments AG, Winterthur, Switzerland) and the signals were A/D converted (Qualisys AB, Gothenburg, Sweden).

Data collection procedure

Data collection was conducted at the 2017 ICF World Championships in Sprint and Paracanoe in Racice, Czech Republic. Prior to data collection the athletes were introduced to the test procedure. All athletes had previous experience with paddling on a kayak ergometer. Athletes were weighed prior to testing. If they wore a prosthesis during the test, the athlete was weighed with the prosthesis. If they did not wear a prosthesis, the athletes were weighed without the prosthesis. Athletes started with performing a ten-minute warm-up at a self-selected intensity. The athletes were then asked to paddle on four different levels for 20 seconds each; 90, 100 and 110 strokes*min^{-1} and at 150 W (females) or 200 W (males). The athletes rested for 5 minutes between each level. Thereafter, the athletes paddled on a race pace intensity level corresponding to the intensity of a 200 m race. The race pace intensity was performed by the athletes first successively increasing their intensity for 10 stroke cycles (catch to catch of the same side) and then paddling at their race pace intensity for 10 stroke cycles. The athletes were asked to maintain this intensity level through visual feedback of the power output on the ergometer display. Kinematic and kinetic data were simultaneously collected and synchronised using the Qualisys Track Manager (Qualisys AB, Gothenburg, Sweden) for all intensity levels. Only the race pace intensity level was used for the analyses in this study.

Data processing

All kinematic and kinetic data analyses were performed in Visual3D (version 6, C-Motion, Inc., Germantown, MD, USA) except for the calculation of paddling power output which was performed in MATLAB (version R2017b, The MathWorks, Inc., Natick, MA, USA). Kinematic data were smoothed with a second-order, bi-directional, low-pass Butterworth filter with a seven Hz cut-off frequency. Kinetic data were smoothed using the same filter but with a cut-off frequency of 20 Hz. The global coordinate system (GCS) was set with a positive X-axis in the direction the athlete was facing, a positive Y-axis directed to the left of the athlete and a positive Z-axis in the vertical direction.

One stroke cycle was defined from catch to catch of the same side and the drag phase was defined as catch to release. The catch was defined as when the paddling power output crossed the zero line from negative to positive. The release was defined as when the marker placed at the ulnar styloid process was in the maximum position in the negative X direction of the GCS. The first ten stroke cycles after reaching the required intensity were used for the data analysis.

Paddle variables

Stroke frequency, cycle time, maximal paddle velocity, time to peak force and drag length were calculated using the markers on the paddle. Maximal paddle velocity and drag length were calculated during the drag phases in the GCS X direction. Mean and maximal paddling force were calculated at each side of the paddle during the drag phase. Since the force curves could have multiple peaks, time to peak force was calculated from catch to the first peak in the force curve. Maximal paddle force was calculated for the largest peak.

Paddling power output was calculated using the method previously described by Bjerkefors et al. (2018, 2019). In short, the power output was defined as the product of the paddle force and the velocity of the force transducer displacement in the direction of the rope connected to the flywheel. The displacement was defined as the magnitude of the vector between the marker attached on the force transducer at the paddle and the virtual marker on the flywheel. In addition, paddle work and paddle impulse during the drag phases at each side were calculated as the integral of power output and paddle force, respectively.

Seat variables

The mean anterior/posterior force and the anterior/posterior and lateral centre of pressure (COP) displacements at the seat were calculated during the drag phases of the A and NA sides.

Footrest variables

Since the transducers at the footrest were placed at an angle relative to the GCS (64° for both footrests for all participants), a rotation matrix was applied in order to align the forces in the same directions as the GCS. The maximal push, pull, medial and lateral forces at the footrest of the A leg and the NA leg were calculated during the drag phase of the A and NA sides.

Joint kinematic and kinetic variables

The segment coordinate systems (SCS) for each segment have previously been described by Rosén et al. (2019). Joint ROM and maximal and minimal joint angular velocities and moments in flexion and extension were calculated for the hip, knee and ankle joints during the stroke cycles (Table 1). The joint angles and joint velocities were calculated using a Cardan/Euler rotation sequence of x, y, z which corresponded to forward flexion, abduction and axial rotation. The joint moments were normalised to body mass and were resolved in the coordinate system of the proximal segment (e.g., knee moment was resolved in the coordinate system of the thigh). Additionally, maximal rotation to the A side and NA side as well as the ROM were calculated for trunk and pelvis rotation and for pelvis rotation.

Statistical analysis

The statistical analyses were carried out in IBM SPSS statistics 26 (IBM, Armonk, NY, USA). All parameters are presented as means ±1 SD. The Shapiro Wilks' W test was performed to test the data for normality. Mean power output, maximal paddle force, mean

Table 1. Joint angle and velocity definitions.

Moving segment	Reference segment	Designated joint movement
Trunk	Global Coordinate System (GCS)	Trunk and pelvis: rotation*
Pelvis	Global Coordinate System (GCS)	Pelvis: rotation
Thigh	Pelvis	Hip: flexion/extension
Shank	Thigh	Knee: flexion/extension
Foot	Shank	Foot: dorsal flexion/plantar flexion

*When the trunk rotation angle is defined in reference to the GCS the calculated angle includes the movement of the pelvis.

paddle force, paddle impulse and paddle work were significantly correlated with body mass, and therefore they were divided by mass for the analysis. For mean power output, maximal paddle velocity, maximal paddle force, mean paddle force, paddle impulse, paddle work, maximal trunk and pelvis rotation, maximal pelvis rotation, drag length, cycle time, time to peak paddle force, mean, maximal and minimal posterior force at the seat, anterior/posterior and lateral COP at the seat and hip flexion/extension ROM, angular velocity and moment, which met the assumption of equality ($p < .05$), a two-way mixed model analysis of variance (ANOVA) with one between-group factor *group* (AK, BK) and one within group factor *side* (A, NA) was performed. For two variables, hip extension moment and paddle work which were not normally distributed, the above mentioned ANOVA was conducted on the ranked data. Furthermore, independent *t*-tests were performed to examine differences between groups for stroke frequency, trunk and pelvis rotation ROM and pelvis rotation ROM, and for the NA side for knee and ankle flexion ROM, angular velocity and moment and for medial/lateral and push/pull NA footrest forces during the drag phase of the A and NA sides. The independent *t*-test for knee flexion/extension ROM and knee extension moment were conducted on log transformed data. The *t*-test statistics and p value for these variables are reported from the log transformed data whilst the 95% CI for mean differences have been back transformed. A Mann-Whitney U test was performed for knee flexion angular velocity. Levene's test for equality was conducted to examine if the group variances were equal in the population. Significant interactions were followed up with Bonferroni post-hoc tests. The significance level was set at $p \leq .05$. Ninety-five per cent confidence intervals (CI) and effect size for mean differences are reported. Partial eta-squared (η_p^2) was calculated as an estimate of effect size for the mixed model ANOVAs and Cohen's *d* was calculated for independent t-tests. Effect sizes were considered as small (>.01), medium (>.06) and large (>.14) for η_p^2 and as small (>.2), medium (>.5) and large (>.8) for Cohen's *d* (Cohen, 1988).

Results

Paddle variables

No main effects for either side or group were seen for any of the paddle variables; power output, mean paddle force, maximal paddle force, paddle work, paddle impulse, maximal paddle velocity, cycle time, time to peak paddle force and drag length (Table 2). Furthermore, there was no significant interaction (*group* x *side*) for any of the paddle variables. No significant difference in stroke frequency were seen between the groups (132 ± 13, and 135 ± 21 strokes·min^{-1} for AK and BK, respectively). The paddling power output normalised during the drag phase for AK and BK athletes and for A and NA sides are shown for visualisation purposes in Figure 2.

Seat and footrest variables

A main effect of side was seen in the maximal, minimal and mean posterior forces at the seat but not for the anterior/posterior or lateral COP displacement (Table 2). No main effect was seen for group and there was no significant interaction (*group* × *side*) for any of the variables at the seat.

Table 2. Kinematic and kinetic variables during kayak ergometer paddling at a 200 m race pace intensity for the amputated (A) and non-amputated (NA) side in athletes with unilateral above knee (AK) or below knee (BK) amputation.

		AK		BK		Significance			Side effect			Group effect		
		A	NA	A	NA									
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Side	Grp.	Int.	F	p	η_p^2	F	p	η_p^2
Paddle	Mean power output (W/kg)	5.50 ± 1.10	5.77 ± 1.03	5.31 ± 1.79	5.67 ± 1.33				2.14	0.16	0.13	0.06	0.81	0.00
	Mean force (N/kg)	1.53 ± .22	1.54 ± .19	1.44 ± .38	1.53 ± .21				0.68	0.42	0.04	0.23	0.64	0.02
	Max force (N/kg)	3.29 ± .54	3.38 ± .56	2.97 ± .55	3.11 ± .35				1.18	0.29	0.07	1.50	0.24	0.09
	Work (J/kg)	2.57 ± .43	2.60 ± .36	2.38 ± .58	2.52 ± .33				0.12	0.74	0.08	0.05	0.83	0.00
	Impulse (Ns/kg)	0.61 ± .09	0.62 ± .09	0.56 ± .10	0.59 ± .07				0.57	0.46	0.04	1.10	0.31	0.07
	Max velocity (m/s)	4.85 ± .57	4.92 ± .50	4.29 ± 2.17	4.34 ± 2.20				1.41	0.25	0.09	0.71	0.41	0.05
	Cycle time (s)	0.919 ± .099	0.918 ± .099	0.916 ± .143	0.915 ± .142				0.26	0.62	0.02	0.00	0.95	0.00
	Time to peak paddle force (s)	0.140 ± .045	0.136 ± .040	0.126 ± .036	0.135 ± .038				0.21	0.66	0.01	0.14	0.71	0.01
	Drag length (m)	1.484 ± .117	1.477 ± .106	1.491 ± .090	1.438 ± .069				0.97	0.34	0.06	0.14	0.71	0.01
Seat	Max pos force (N)	202 ± 76	327 ± 91	221 ± 76	334 ± 83	*			20.55	0.00	0.58	0.15	0.70	0.01
	Min pos force (N)	−94 ± 72	99 ± 59	6 ± 99	88 ± 61	*			26.81	0.00	0.64	3.29	0.09	0.18
	Mean pos force (N)	23 ± 52	217 ± 65	110 ± 97	219 ± 67	*			37.35	0.00	0.71	3.48	0.08	0.19
	COP ant/pos displacement (m)	0.065 ± .023	0.048 ± .019	0.056 ± .012	0.043 ± .027	*			5.59	0.03	0.27	0.78	0.39	0.05
	COP lateral displacement (m)	0.077 ± .022	0.071 ± .016	0.082 ± .027	0.083 ± .020				0.26	0.62	0.02	0.77	0.40	0.05
Joint kinematics and kinetics	Max trunk rot (°)	34 ± 10	32 ± 8	40 ± 5	37 ± 4				2.64	0.13	0.15	2.24	0.16	0.13
	Max pelvis rot (°)	17 ± 9	9 ± 5	17 ± 5	17 ± 3				4.00	0.06	0.21	3.09	0.10	0.17
	Hip flex/ext ROM (°)	10 ± 4	14 ± 4	23 ± 9	18 ± 3		#		0.08	0.78	0.01	23.12	0.00	0.62
	Hip flex velocity (°/s)	78 ± 24	83 ± 23	115 ± 41	103 ± 23		#		0.23	0.64	0.02	6.03	0.03	0.30
	Hip ext velocity (°/s)	76 ± 29	82 ± 25	136 ± 74	99 ± 22		#		1.13	0.31	0.07	7.75	0.02	0.36
	Hip flex moment (Nm/kg)	0.32 ± .36	1.11 ± .19	0.97 ± .45	1.14 ± .27	*	#	¤	24.32	0.00	0.65	5.74	0.03	0.31
	Hip ext moment (Nm/kg)	0.12 ± .32	0.13 ± .33	0.08 ± .32	−.06 ± .35				0.02	0.89	0.01	0.16	0.70	0.01

The values presented are the group means ±1 standard deviation (SD). ant = anterior, pos = posterior, COP= Centre of pressure, rot=rotation, flex= flexion, ext= extension, Grp = group, Int = interaction, η_p^2 = partial eta squared, *main effect of side, #main effect of group, ¤significant interaction (group × side).

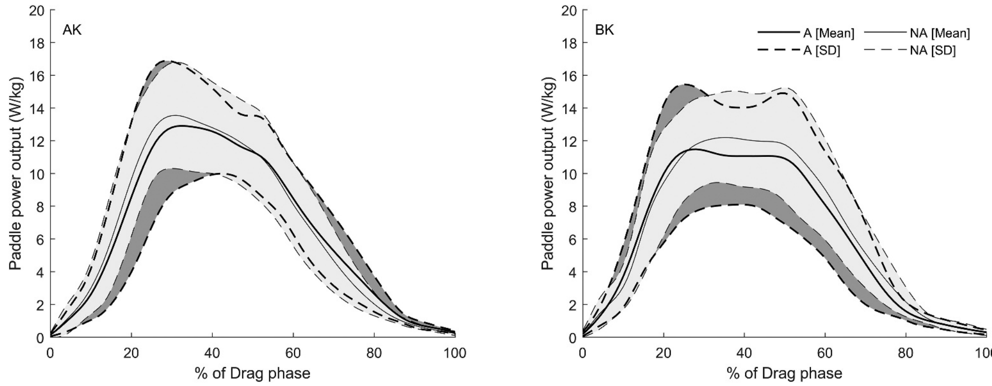

Figure 2. Paddle power output during the drag phase for the athletes with above knee (AK) amputation (left) and below knee (BK) amputation (right). Data from the amputated (A) and non-amputated (NA) sides are shown as mean (solid line) and ±1 standard deviation (spaced lines). the dark coloured area represents the mean ±1 standard deviation for the a side and the light coloured area represents the mean ±1 standard deviation for the NA side.

No significant differences between the groups were found for the medial, lateral, push or pull footrest forces for the NA side during the A or NA drag phase (Table 3).

Joint kinematic and kinetic variables

A significant main effect of group was seen for the hip joint in flexion/extension ROM, in flexion and extension angular velocity and in flexion moment where the BK group demonstrated significantly larger values compared to the AK group (Table 2). Furthermore, for hip flexion moment a main effect was also seen in side and a significant interaction (*group* x *side*) was observed (F(1,15) = 10.120, p = .007, ${\eta_p}^2$ = .438). The results of the post-hoc tests showed that the AK group had significantly smaller hip flexion moment compared to the BK group in the A side with a mean difference of −.648 (95% CI −1.106 to −.190, p = .009) Nm/kg. The results also showed that for the AK group, the hip flexion moment at the A side was significantly smaller compared to the NA side with a mean difference of −.789 (95% CI −1.031 to −.546, p < .001) Nm/kg. For descriptive purposes, graphs of hip moment, hip velocity and hip ROM normalised to a stroke cycle are shown in Figures 3-5.

There were no significant differences between the groups in trunk rotation ROM (AK = 66 ± 16°, BK = 76 ± 8°; t (15) = > −1.497, p = .155, d = .76) or in pelvis rotation ROM (AK = 26 ± 11°; BK = 34 ± 6°; t (15) = > −1.751, p = .100, d = .89). No significant differences between the groups were seen for the NA side in joint ROM, joint angular velocity or joint moment for either the knee or ankle (Table 3).

Discussion and implications

This study examined the differences in kinematic and kinetic performance variables during kayak ergometer paddling between international level para-kayak athletes with AK and BK amputation as well as between the A and NA sides. On the contrary to the

Table 3. Kinematic and kinetic variables during kayak ergometer paddling at a 200 m race pace intensity for the amputated (A) and non-amputated (NA) side in athletes with unilateral above knee (AK) or below knee (BK) amputation. Independent *t*-test results, effect sizes and 95% confidence intervals (95% CI) are reported for the differences between the AK and BK groups for the variables on the NA side.

		AK		BK					
		A	NA	A	NA				
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	t	*p*	*d*	95% CI (lower; upper)
Footrest	Max push force A side drag (N)	179 ± 48[a]	-	393 ± 187[b]	-				
	Max pull force A side drag (N)	-	187 ± 84	-	241 ± 62	−1.317	0.191	0.70	−138; 30
	Max push force NA side drag (N)	-	373 ± 135	-	427 ± 172	0.713	0.487	0.36	−107; 214
	Max pull force NA side drag (N)	140 ± 71[a]	-	180 ± 80[b]	-				
	Max med force A side drag (N)	25 ± 20[a]	85 ± 30	50 ± 20[b]	75 ± 39	0.639	0.533	0.32	−25; 46
	Max lat force A side drag (N)	29 ± 23[a]	109 ± 30	29 ± 9[b]	74 ± 36	2.103	0.053	1.07	−.5; 70
	Max med force NA side drag (N)	23 ± 0[a]	100 ± 27	41 ± 34[b]	79 ± 19	1.762	0.098	0.89	−5; 48
	Max lat force NA side drag (N)	9 ± 3[a]	72 ± 39	20 ± 10[b]	49 ± 31	1.221	0.241	0.62	−17; 62
Joint kinematics and kinetics	Knee flex/ext ROM (°)[#]	13 ± 1[a]	30 ± 11	38 ± 11[b]	36 ± 3	−2.133	0.056	0.80	0.6; 1.0
	Knee flex velocity (°/s)	55 ± 3[a]	140 ± 54	155 ± 38[b]	155 ± 20	23.00 [U]	0.315		
	Knee ext velocity (°/s)	97 ± 30[a]	135 ± 55	204 ± 52[b]	158 ± 25	0.945	0.359	0.48	−29; 74
	Knee flex moment (Nm/kg)	0.02 ± .08[a]	0.20 ± .17	0.19 ± .23[b]	0.15 ± .16	0.590	0.564	0.06	−.1; .2
	Knee ext moment (Nm/kg)[#]	0.26 ± .12[a]	0.58 ± .22	0.32 ± .24[b]	0.51 ± .28	1.014	0.327	0.51	0.78; 2.01
	Ankle flex/ext ROM (°)	3 ± 0[a]	18 ± 8	12 ± 11[b]	19 ± 2	−.657	0.513	0.34	−7; 4
	Ankle flex velocity (°/s)	30 ± 9[a]	85 ± 36	65 ± 36[b]	97 ± 18	−.733	0.475	0.37	−45; 22
	Ankle ext velocity (°/s)	35 ± 9[a]	89 ± 31	81 ± 44[b]	89 ± 20	−.046	0.964	0.02	−31; 30
	Ankle flex moment (Nm/kg)	0.21 ± .08[a]	0.25 ± .14	0.15 ± .16[b]	0.19 ± .14	0.891	0.387	0.01	−.1; .2
	Ankle ext moment (Nm/kg)	0.23 ± .03[a]	0.40 ± .20	0.29 ± .34[b]	0.32 ± .28	−.669	0.514	0.13	−.3; .2

The values presented are the group means ±1 standard deviation (SD).[#]statistics were conducted on log transformed data,[U] the U score from the Mann-Whitney U test is reported, [a] the mean and SD presented are only for 2 of the 11 AK athletes, [b]the mean and SD presented are only for 5 of the 6 BK athletes; med= medial, lat= lateral, flex= flexion, ext= extension.

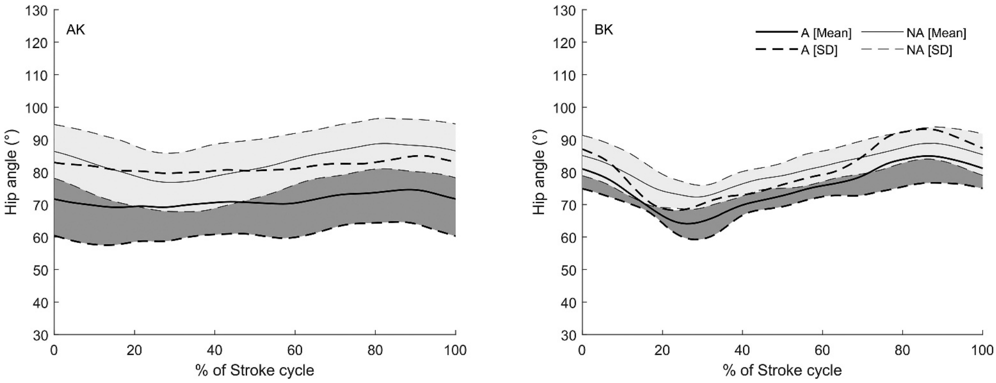

Figure 3. Hip flexion/extension angle normalised during the stroke cycle for the athletes with above knee (AK) amputation (left) and below knee (BK) amputation (right). Data from the amputated (A) and non-amputated (NA) sides are shown as mean (solid line) and ±1 standard deviation (spaced lines). the dark coloured area represents the mean ±1 standard deviation for the a side and the light coloured area represents the mean ±1 standard deviation for the NA side. Positive values indicate flexion and negative values indicate extension.

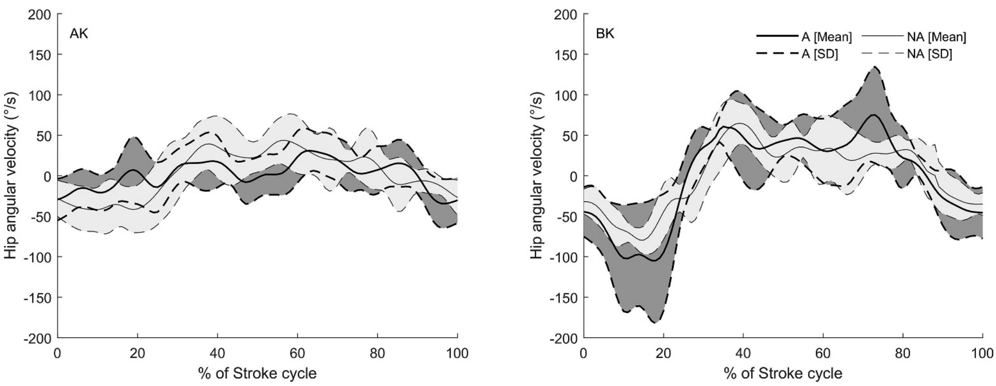

Figure 4. Hip flexion/extension angular velocity normalised during the stroke cycle for the athletes with above knee (AK) amputation (left) and below knee (BK) amputation (right). Data from the amputated (A) and non-amputated (NA) sides are shown as mean (solid line) and ±1 standard deviation (spaced lines). the dark coloured area represents the mean ±1 standard deviation for the a side and the light coloured area represents the mean ±1 standard deviation for the NA side. Positive values indicate flexion and negative values indicate extension.

hypothesis, the results showed that there were no significant differences between the two groups in any of the main performance variables such as paddling power output, paddling force or paddling velocity. Differences between the two groups were only seen in hip flexion/extension ROM, hip flexion and extension angular velocity and in hip flexion moment. Significant differences between the A and NA sides were observed in maximal, minimal and mean posterior force at the seat and in hip flexion moment.

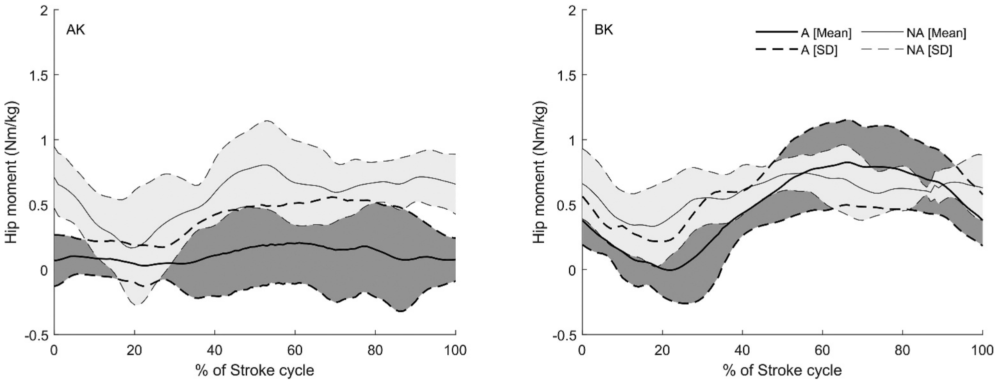

Figure 5. Hip flexion/extension moment normalised during the stroke cycle for the athletes with above knee (AK) amputation (left) and below knee (BK) amputation (right). Data from the amputated (A) and non-amputated (NA) sides are shown as mean (solid line) and ±1 standard deviation (spaced lines). the dark coloured area represents the mean ±1 standard deviation for the a side and the light coloured area represents the mean ±1 standard deviation for the NA side. Positive values indicate flexion and negative values indicate extension.

It was fairly unexpected that no significant differences were observed between the two groups in any of the main performance variables. Previous studies have indicated that the legs play a significant role for performance in elite sprint kayaking (Bjerkefors et al., 2018; Brown et al., 2011; Nilsson & Rosdahl, 2016) where especially a larger hip and knee flexion and extension ROM have shown to be important (Bjerkefors et al., 2018). The connection with the footrest and the flexion and extension movement of the knee helps the pelvis and trunk to rotate which contributes to paddling propulsion (Begon et al., 2010; Limonta et al., 2010; Michael et al., 2009; Nilsson & Rosdahl, 2016). Bjerkefors et al. (2019) found a significant difference between KL3 and AB athletes in trunk and pelvis rotation. It was concluded that since five of the nine KL3 athletes with amputation did not wear a prosthesis, this may decrease the ability to push and pull on the footrest resulting in a significantly smaller trunk and pelvis rotation compared to AB athletes. In our study, however, no significant difference in either trunk and pelvis rotation or pelvis rotation was found between the AK and BK athletes, even though the majority of the AK athletes did not wear a prosthesis. The non-significant results suggest that there does not necessarily need to be a contact with the footrest to be able to rotate the trunk specifically. The AK athletes who did not use a prosthesis used the custom-made adaptation for the residual limb which provides a connection with the ergometer as well as a resistance which facilitated trunk rotation. Locking the residual limb into this adaptive equipment may however be a reason for why the AK athletes, although not significant, demonstrated less maximal pelvis rotation at the NA side (NA side: 9 ± 5°; A side: 17 ± 9°).

In our study, the only significant differences between the groups were found in variables concerning the hip joint. Since the BK athletes have two full functioning knee joints, and usually wear a prosthesis when paddling, it enables them to also flex and extend the hip joint. The AK athletes, who lock their residual limb into the adaptive device, restricts their ability to use the hip joint and to fully rotate the pelvis. It instead enables them to transfer momentum and force onto the adaptive device and the kayak in connection with the paddle action.

Since only two AK athletes wore a prosthesis it limited the possibility to examine differences in forces at the footrest and in knee and ankle joint kinetics and kinematics between the A and NA sides and between the groups in the A side. Although no statistical analyses could be performed for these variables for the A side, it is evident that there are large numerical differences between the BK group and the two athletes using a prosthesis in the AK group. The two AK athletes have smaller numerical values in the A side compared to the BK group in all knee and ankle joint values except for ankle flexion moment. The result that the hip joint variables show significant differences between the groups in the A side, indicates that it is possible that there would be differences in the other joints as well.

Both the AK and BK groups show similar values in hip, knee and ankle flexion ROM as previously reported values of KL3 athletes (Bjerkefors et al., 2019). The BK group shows slightly higher values, although not significant, in the NA side compared to the AK group indicating that the higher amputation may affect the technique of the NA side. This might be due to a balance compensation as the kayak would turn in the direction of the A side if there was a larger side difference.

A difference between the A and NA sides were seen in the posterior force at the seat. The results showed that the posterior force during the drag phase of the A side was smaller compared to the NA side. For the AK athletes, an anterior force could be seen for the A side. This might be a result of the majority of the athletes not wearing a prosthesis leading to the inability to push on the footrest during the drag phase of that side. This means that there is only a pull force on the footrest of the NA side resulting in the athletes gliding anteriorly on the seat, thus creating an anterior force.

Only two of the 11 athletes in the AK group wore a prosthesis during the study. This also reflects what is seen during paracanoe competitions, where many unilateral and bilateral AK athletes choose to paddle without prosthesis and lock their residual limbs in devices connected to the kayak. Ellis et al. (2018) found that when a recreational AK paracanoe athlete paddled without a prosthesis, an increase in stroke rate, stroke speed and power output was observed. Even though this was a case study and it was conducted on a recreational paracanoe athlete, it may give some indication to why many AK athletes choose paddle without a prosthesis.

Neither the numerical (but not significant) differences between the groups in some variables nor the significant differences in the hip variables significantly affected the performance as no differences were found in the paddling performance variables. The results from this study therefore seem to indicate that AK and BK para-kayak athletes can continue to compete in the same classification class. However, as the sport is quite new and the population of AK and BK para-kayak athletes is quite small, there is a potential for the athletes' technique to evolve as well as for the population to grow. It is therefore of interest to continue to examine the differences between these two groups in the future.

For standardisation and instrumentation we elected to use a kayak ergometer, which may hinder the transferability of our findings to data gathered while kayaking on water. Future research should gather data during paddling on water, since balance is a key aspect of kayak performance that not only differs between groups but also is not factored when using a kayak ergometer. In addition, data should preferably be collected during a whole 200 m race to examine the effect of fatigue on the kinematic and kinetic performance variables. Additionally, as with most Para sport research, the population size of international level AK and BK para-kayak athletes is not large, yet we were pleased to have gathered data from 44% of the total population.

Conclusion

The study examined differences in kinematic and kinetic performance variables between para-kayak athletes with unilateral AK and BK amputation as well as between the A and NA sides. The results showed that there were only significant differences between the groups in the hip joint in flexion/extension ROM, flexion and extension angular velocity and flexion moment. Differences between the sides were seen in posterior force at the seat and in hip flexion moment. The limited number of variables in which differences between the groups were observed indicate that athletes with AK and BK amputation may continue to compete in the same class. It would however be preferable if the study could be reproduced on water with a larger sample size before any definite conclusions can be drawn.

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Disclosure statement

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